WADC TECHNICAL REPORT 52-52

WATERMAN TYPE I HYDRAULIC QUANTITY MEASURING FUSE

HOWARD R. DAVIES
AIRCRAFT LABORATORY

MARCH 1952

WRIGHT AIR DEVELOPMENT CENTER

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The information furnished herewith is made available for study upon the understanding that the Government's proprietary interests in and relating thereto shall not be impaired. It is desired that the Judge Advocate (WCJ), Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, be promptly notified of any apparent conflict between the Government's proprietary interests and those of others.

The U.S. Government is absolved from any litigation which may ensue from the contractor's infringing on the foreign patent rights which may be involved.

WADC TECHNICAL REPORT 52-52

WATERMAN TYPE I HYDRAULIC QUANTITY MEASURING FUSE

Howard R. Davies
Aircraft Laboratory

March 1952

RDO No. R-452-495

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Wright Air Development Center under RDO No. R-452-495, Hydraulic and Pneumatic System Components Development, as a part of the project initiated for the purpose of qualifying and standardizing on a type or types of a hydraulic quantity measuring fuse. The work was administered under the direction of the Aircraft Laboratory, Mechanical Branch, Wright Air Development Center. Howard R. Davies was the project engineer. This report is the final report covering the qualification testing of the Waterman, Type I, Hydraulic Fuse, in the sizes listed in the following report.

ABSTRACT

A series of hydraulic quantity measuring fuses, Type I, manufactured by the Waterman Engineering Company were subjected to qualification tests in accordance with the applicable specifications. The temperature range investigated was -65°F to +160°F with a fluid flow rate range of 0.1 gpm to 12 gpm. The fluid used was in accordance with Specification MIL-O-5606. It is concluded that the units tested were acceptable for use in aircraft hydraulic systems, containing the above mentioned fluid.

PUBLICATION REVIEW

Manuscript Copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

Jack A. Gibbs

JACK A. GIBBS
Colonel, USAF
Chief, Aircraft Laboratory
Aeronautics Division

TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

The hydraulic quantity measuring fuse is a safety valve designed to isolate ruptured circuits and offer the maximum protection against fire hazards and a complete loss of hydraulic system fluid, in the event of a line or component failure. This valve is used in conjunction with a hydraulic cylinder or valve and functions as a fluid quantity measuring device. The design of the fuse is such that it will pass an amount of fluid in excess of the quantity required for one complete actuation of the fuse protected component. Therefore, when the fluid demand is greater than the above mentioned amount, due to a failure or leak on the downstream side of the fuse, the fuse will close and prevent any further loss of hydraulic fluid in that section of the system.

With the increasing use and demand for the above item, a program to qualify a valve or valves was initiated by the WADC, with the "Waterman", 831-8 fuse being the first one tested.

WATERMAN TYPE I
HYDRAULIC QUANTITY MEASURING FUSES

General Purpose

To determine the operating characteristics of the Waterman, Type I, hydraulic fuse when operated at temperatures of -65° to +160°F and at flow rates of 0.1 to 12 gpm with rated flow being 6 gpm. These tests were conducted in accordance with Specification MIL-F-5508 "Fuses; Aircraft Automatic Quantity Measuring, Hydraulic", dated 23 March 1950.

Summary of Results

The results of the tests indicate that the fuses are in compliance with the applicable Specification MIL-F-5508, with the following exceptions:

a. Volumetric Capacity:

1. Fuse No. 16661 passed an excessive volume of fluid at flow rate of 4 gpm, -65°F temperature.

2. Fuse No. 16674 passed an excessive volume of fluid at flow rates above 2 gpm, normal room temperature.

b. Leakage:

1. Fuses Nos. 16661 and 16667 leaked in excess of the allowable amount during the first minute of the test.

c. Rapid Warm-Up Test:

It was determined from this test that it is necessary to provide a fluid path of 12 feet, (1/2 tube size) upstream, between the fuse and any large quantity of fluid (reservoir, accumulator, large size line, etc.). The fuse and contained oil being small in volume, in comparison to the transfer cylinder and large oil supply, would warm up more rapidly than the larger volume of oil. As a means of preventing this temperature differential and thus a viscosity differential, the 12 foot (1/2 tube size) distance is provided to allow sufficient time for the supply oil to reach the approximate temperature of the fuse prior to its entrance into the fuse body. Therefore, in applications where the fuse is installed less than 12 feet downstream of a fluid reservoir, accumulator, large size tubing, etc. or within a warm compartment less than 12 feet away from the major portion of the fluid a fuse with a volumetric capacity of at least 130% of the required volume, must be used.

Fuses Tested

Manufacturer's Part No.	Capacity Cu. in.
831-8	10
831-8	20
831-8	60
831-8	80
831-8	120

Proof Pressure Test

Test and Purpose: Paragraph 4.5.2 "Proof Pressure" To determine if the subject valve would withstand 1.5 time the nominal working pressure (3000 psi) without evidence of external leakage, failure, distortion of permanent set.

Test Procedure: Fuses Tested: Serial numbers 16661, 16667, and 16674. Hydraulic pressure of 4500 psi was applied to the subject valves and held for 5 minutes.

Test Results: There was no evidence of external leakage, failure, distortion or permanent set of the fuses during the applied pressure (4500psi).

Conclusions: The subject valves comply with Paragraph 4.5.2 of Specification MIL-F-5508.

Leakage Test (Room Temperature)

Test and Purpose: Paragraph 4.5.3 "Leakage". To determine the amount of leakage through the fuse, when a pressure of 40, 80, and 150 psi and 50% and 100% of the working pressure is applied to the upstream side of the subject fuse, when the fuse is closed.

Test Equipment: As shown in Figure 1 and Photograph 1.

Test Procedure: Fuses tested: Serial numbers 16661, 16691, 16674, 16667, 53300, and 167671. With the downstream side of the fuse closed, hydraulic pressures of 40, 80, 150, 1500, and 3000 psi respectively were applied to the upstream side of the fuse, and the leakage was measured at the downstream side.

Test Results: Refer to Table I page 4.

Conclusions: The subject valves comply with Paragraph 4.5.3 of Specification MIL-F-5508.

TABLE I

Leakage Test Results (Room Temperature)

Fuse No. 167671 Volumetric Capacity 20 in.^{3}

Pressure psi	Leakage drops/minute
40	0
80	0
150	0
1500	0
3000	0

Fuse No. 16667 Volumetric Capacity 80 in.^{3}

Pressure psi	Leakage drops/minute
40	4
80	2
150	0
1500	0
3000	0

Fuse No. 16674 Volumetric Capacity 120 in.^{3}

Pressure psi	Leakage drops/minute
40	2
80	1
150	0
1500	0
3000	0

Fuse No. 16691 Volumetric Capacity 10 in.^{3}

Pressure psi	Leakage drops/minute
40	3
80	1
150	1
1500	0
3000	0

Fuse No. 53300 Volumetric Capacity 60 in.^{3}

Pressure psi	Leakage drops/minute
40	0
80	0
150	0
1500	0
3000	0

Volumetric Capacity Test (Room Temperature)

Test and Purpose: Paragraph 4.5.4 "Volumetric Capacity". To determine operating characteristics of the subject valve at normal temperatures with nominal working pressure and with low pressure.

Test Equipment: As shown in Figure 2 and Photograph 2.

Test Procedure: Fuses tested: Serial numbers 16661, 166674, 16691, 53300, and 16667. The fuses were operated at various rates of flow at low pressure with the set up as shown in Figure 2 and Photograph 2. The fuses were then operated at various rates of flow at 3000 psi pressure, using a relief valve and check valve in return line.

Test Results: Volumetric results are as shown on Figure 11, 12, 13, 14, 15, 16, 17, and 18 and as tabulated in Table 2 pages 6 and 7.

Conclusions: The subject valves comply with Paragraph 4.5.4, of Specification MIL-F-5508, except as follows:

(a) Room temperature, 3000 psi pressure and flow rates above 2 gpm (Fuse No. 16674, Figure 17).

TABLE II

Volumetric Capacity Test Results (Room Temperature)

UNRESTRICTED FLOW
Volumetric Capacity 20 in^3

Fuse # 16661

Volume in^3	Time of Cycle Sec	Flow GPM	Fluid Temp °F	Room Temp °F	Pressure psi
24	17	.35	80	75	16
24.3	12.4	.61	80	75	16
24.2	4.4	1.25	80	75	22
24.4	2.2	3.00	80	75	42
22.5	1.1	6.00	80	75	125
23	.7	12.00	80	75	300

RESTRICTED FLOW
Bypass closed - Relief Valve Set at 3000 psi

Volume in^3	Time of Cycle Sec	Flow GPM	Fluid Temp °F	Room Temp °F	Pressure psi
22.5	31.0	0.7	92	75	3000
24.2	7.0	1.5	95	75	3000
23.8	2.8	3.0	96	75	3000
22.7	1.2	6.0	98	75	3000

UNRESTRICTED FLOW
Volumetric Capacity 80 in^3

Fuse # 16667

Volume in^3	Time of Cycle Sec	Flow GPM	Fluid Temp °F	Room Temp °F	Pressure psi
88.1	92	.25	78	78	16
81.8	42	.6	78	78	20
87.8	14	1.5	78	78	35
86.8	6.6	3.0	78	78	75
86.0	3.6	6.0	78	78	--
87.5	1.8	12.0	78	78	--

RESTRICTED FLOW
Bypass closed - Relief Valve set at 3000 psi

Volume in^3	Time of Cycle sec	Flow GPM	Fluid Temp °F	Room Temp °F	Pressure psi
86.8	105	.6	100	78	3000
85.6	18.5	1.5	90	78	3000
86.8	8.4	3.0	95	78	3000
86.2	3.8	6.0	97	78	3000

TABLE II (CONTINUED)

UNRESTRICTED FLOW

Fuse # 16674 Volumetric Capacity 120 in^3

Volume In^3	Time of Cycle Sec	Flow GPM	Fluid Temp °F	Room Temp °F	Pressure PSI
118	430.0	0.25	78	78	10
124	57.0	0.6	78	78	15
141	22.0	1.5	78	78	23
135	11.0	3.0	78	78	45
136	5.4	6.0	78	78	160
145	3.2	12.0	78	78	650

RESTRICTED FLOW

Bypass closed - Relief Valve set at 3000 psi

Volume In^3	Time of Cycles Sec	Flow GPM	Fluid Temp °F	Room Temp °F	Pressure PSI
126	205	.5	88	78	3000
139	33	1.5	90	78	3000
147	15	3.0	96	78	3000
141	6.5	6.0	104	78	3000

RESTRICTED FLOW

Bypass closed - Relief Valve set at 3000 psi

Fuse # 12344 Volumetric Capacity 60 in^3

Volume In^3	Time of Cycles Sec	Flow GPM	Room Temp °F	Pressure PSI
100	190	.1	78	3000
102	170	.15	78	3000
70	35	0.50	78	3000
65	10	2.0	78	3000
65	8	3.0	78	3000
63	3	10.0	78	3000

RESTRICTED FLOW

Bypass closed - Relief Valve set at 3000 psi

Fuse # 1691 Volumetric Capacity 10 in^3

Volume In^3	Time of Cycles Sec	Flow GPM	Room Temp °F	Pressure PSI
12.2	30	.1	78	3000
11.1	8	.4	78	3000
11.0	2	1.5	78	3000
11.0	1	3.0	78	3000
11.0	1/2	6.0	78	3000

Pressure Drop Test

Test and Purpose: Paragraph 4.5.5, "Pressure Drop". To determine pressure drop through the fuse in each direction and at various rates of flow.

Test Equipment: As shown in Figure 3 and Photograph 3.

Test Procedure: Fuses tested: Serial numbers 16661, 16679, and 16691. The fuses were tested for pressure drop in both directions at flow rates of 1.5, 3.0, 6.0 and 12.0 GPM and at both low pressure and at rated inlet pressure. The pressure drop was measured by a differential pressure indicator.

In order to prevent closing of the fuse, the piston, (see Figure 19) was removed from the fuse while testing in the normal flow direction. The piston remained out for the pressure drop test in the resetting direction in all tested fuses with the exception of the #16691, 10 in^3 fuse, which was tested with all internal parts intact.

Pressure drop was also measured on a piece of straight tube equivalent in length to the fuse and end connections, between the points at which pressure were taken.

Test Results: As tabulated in Table III Pages 9 and 10.

Conclusion: The subject valves comply with Paragraph 4.5.5 of Specification MIL-F-5508. NOTE: The pressure drop in fuse #16679 in the resetting direction was in excess of the allowable value at rated flow, due to the fact that the piston was removed allowing the spring and check, Figure 19, to move to to top of the fuse and increase the flow path and pressure drop of the fluid. The results for the #16691 10 in^3 fuse, with the piston intact, were well within the specified limits.

TABLE III

Pressure Drop Test Results

Fuse # 16661 Volumetric Capacity 20 in^3

Closing Direction

Pressure PSI	Flow GPM	Pressure Drop PSI
No Restriction	1.5	11.0
3000		10.0
No restriction	3.0	13.0
3000		12.0
No restriction	6.0	25.0
3000		20.0
No restriction	12.0	98.0
3000		88.0

Resetting Direction

Pressure PSI	Flow GPM	Pressure Drop PSI
No restriction	1.5	7.0
3000		6.0
No restriction	3.0	11.0
3000		9.0
No restriction	6.0	25.0
3000		21.0
No restriction	12.0	80.0
3000		72.0

Fuse # 16679 Volumetric Capacity 160 in^3

Closing Direction

Pressure PSI	Flow GPM	Pressure Drop PSI
No restriction	1.5	10.5
3000		6.5
No Restriction	3.0	13.0
3000		12.0
No restriction	6.0	26.0
3000		22.0
No restriction	12.0	99.0
3000		88.0

TABLE III (CONTINUED)

Pressure Drop Test Results

Fuse # 16679 Volumetric Capacity 160 in^3

Resetting Direction

Pressure PSI	Flow GPM	Pressure Drop PSI
No restriction	1.5	7.5
3000		10
No restriction	3.0	14
3000		13
No restriction	6.0	31
3000		24
No restriction	12.0	95
3000		75

Fuse # 16691 Volumetric Capacity 10 in^3

Resetting Direction

Pressure PSI	Flow GPM	Pressure Drop PSI
10	1.5	6.0
15	3.0	8.0
37	6.0	16.5
128	12.0	57.5

Fuse replaced by equal length of tubing for tare readings

Flow GPM	Pressure Drop (no restriction) PSI	Pressure Drop (3000 PSI inlet) PSI
1.5	0.5	No reading
3.0	1.0	No reading
6.0	2.0	1.5
12.0	7.0	6.5

Extreme Temperature Test (High Temperature)

Test and Purpose: Paragraph No. 4.5.6 "Extreme Temperature Operation", Part A. To determine operating characteristics of the subject valve tested at 160°F ambient temperature.

Test Equipment: As shown in Figure 4.

Test Procedure: Fuses tested: Serial Numbers 16661, 16674, 16691, 53300, and 16667. The fuses were exposed to the specified high temperature for a period of 6 hours and were then subjected to Leakage tests and tests for volumetric capacity at flow rates of 1, 1.5, and 6 gpm.

Test Results: As shown by tabulations in Table IV and V on pages 12, 13 and 14 and in Figures 11, 15 and 18.

Conclusions: The subject valves comply with Paragraph 4.5.6(a) of Specification MIL-F-5508.

TABLE IV

Extreme Temperature Test Results (High Temperature)

Fuse # 16661 Volumetric Capacity 20 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	160	0
80	160	0
150	160	0
1500	160	0
3000	160	0

Fuse # 16691 Volumetric Capacity 10 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	160	3
80	160	2
150	160	0
1500	160	0
3000	160	0

Fuse # 53300 Volumetric Capacity 60 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	160	0
80	160	0
150	160	0
1500	160	0
3000	160	0

Fuse # 16667 Volumetric Capacity 80 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	160	1
80	160	1
150	160	0
1500	160	0
3000	160	0

TABLE IV (CONTINUED)

Extreme Temperature Test Results

Fuse # 16674 Volumetric Capacity 120 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	160	2
80	160	1
150	160	0
1500	160	0
3000	160	0

TABLE V

Extreme Temperature Test Results (High Temperature)

Fuse # 16661 Volumetric Capacity 20 in^3

Volumetric Capacity Test

Volume in^3	Time Sec	Flow GPM	Fluid Temp °F	Room Temp °F
23.1	5.2	1	160	160
23.4	3.6	1.5	160	160
23.1	0.9	6	160	160

Fuse # 16667 Volumetric Capacity 80 in^3

Volumetric Capacity Test

Volume in^3	Time Sec	Flow GPM	Fluid Temp °F	Room Temp °F
88.7	19	1	160	160
87.5	13	1.5	160	160
88.9	3.8	6.0	160	160

Fuse # 16674 Volumetric Capacity 120 in^3

Volumetric Capacity Test

Volume in^3	Time Sec	Flow GPM	Fluid Temp °F	Room Temp °F
143	32	1	160	160
142	13	2.5	160	160
142	21	1.5	160	160
141	11	3.1	160	160
142	6	6.0	160	160

Extreme Temperature Test (Low Temperature)

Test and Purpose: Paragraph 4.5.6(b) "Extreme Temperature Operation". To determine operating characteristics of the subject valve tested at -65°F ambient temperature.

Test Procedure: Fuses tested: Serial numbers 16661, 16674, 16691, 53300, 16667, and 67671. The fuses were exposed to the specified low temperature for a period of 72 hours and then subjected to leakage tests for volumetric capacity at flow rates of 1, 1.5, and 6 gpm.

Test Results: As shown by tabulation in Tables VI and VII on pages 16, 17, 18, and 19 and on Figures 11, 15, and 18.

Conclusions: The subject valves comply with Paragraph 4.5.6(b) of Specification MIL-F-5508, with the following exceptions:

a. The first minute of the leakage test on the # 16661 and # 16667 fuses (consult Page 16 Table VI for the amount of excess leakage.)

b. High capacity at flow rate of 4 gpm fuse # 16661 Figure 11.

NOTE: The low temperature results of fuse # 16674, Figure 18, show a high volumetric capacity at the flow rates of above 6 gpm.

TABLE VI

Extreme Temperature Test Results (Low Temperature)

Fuse # 16661 Volumetric Capacity 20 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	-65	10
80	-65	3
150	-65	0
1500	-65	0
3000	-65	0

Fuse # 16667 Volumetric Capacity 80 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	-68	15
80	-68	4
150	-68	1
1500	-68	0
3000	-68	0

Fuse # 16674 Volumetric Capacity 120 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	-65	0
80	-65	0
150	-65	0
1500	-65	0
3000	-65	0

Fuse # 16691 Volumetric Capacity 10 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	-65	3
80	-65	1
150	-65	0
1500	-65	0
3000	-65	0

TABLE VI (CONTINUED)

Extreme Temperature Test Results (Low Temperature)

Fuse # 53300 Volumetric Capacity 10 in^3

Leakage Test Pressure PSI	Temperature °F	Leakage drops/minute
40	-65	0
80	-65	0
150	-65	0
1500	-65	0
3000	-65	0

TABLE VII

Extreme Temperature Test Results (Low Temperature)

UNRESTRICTED FLOW

Fuse # 16661 Volumetric Capacity 20 in^3

Volumetric Capacity Test

Volume in^3	Time Sec	Flow GPM	Fluid Temperature °F	Room Temperature °F
26	9.4	.72	-68	-68
25	4.2	1.55	-68	-68
27	1.8	3.9	-68	-68

UNRESTRICTED FLOW

Fuse # 16667 Volumetric Capacity 80 in^3

Volumetric Capacity Test

Volume in^3	Time Sec	Flow GPM	Fluid Temperature °F	Room Temperature °F
85	29	.76	-68	-68
87	15	1.5	-68	-68
85	4.4	5.0	-68	-68
90	4.5	5.2	-68	-68

RESTRICTED FLOW

Fuse # 16674 Volumetric Capacity 120 in^3

Volumetric Capacity Test

Volume in^3	Time Sec	Flow GPM	Fluid Temperature °F	Room Temperature °F
123	76	.42	-68	-68
137	42	.85	-68	-68
133	8	4.3	-68	-68
140	7	4.7	-68	-68
182	7	6.8	-68	-68
162	3.8	11	-68	-68

TABLE VII (CONTINUED)

Extreme Temperature Test Results (Low Temperature)

UNRESTRICTED FLOW

Fuse # 16691 Volumetric Capacity 10 in^3

Volumetric Capacity Test

Volume in^3	Time Sec	Flow GPM	Fluid Temperature °F	Room Temperature °F
11.2	1	2.9	-65	-65
11.3	2	1.5	-65	-65
11.3	3	1.0	-65	-65

Extreme Temperature Test (Rapid Warm-Up)

Test and Purpose: Paragraph 4.5.6(c) "Extreme Temperature Operation". To determine operating characteristics of the subject valve, with fuse and fluid temperature differentials.

Test Equipment: As shown by Figure 4.

Test Procedure: Fuses tested: Serial numbers - 16667, 16661, 16674, 16691, 67671 and 53300. Following the low temperature test, cylinders and fuse were then removed from the cold room and allowed to warm up as rapidly as room temperature would allow. The hydraulic system was then operated at regular intervals at 6 gpm flow and records made of the actuation time and fluid volume passed.

Test Results: As shown by tabulations in Table VIII Pages 21 and 22. These results indicate a tendency for the valve to fuse at a volumetric capacity that is less than acceptable. This failure to conform to the specification is explained as follows: The cavity "A" on Figure 19 is continually full of oil, and this oil being of a small quantity would warm-up much more rapidly than the large quantity of oil located in the transfer cylinder. The warmer fluid being less viscous than the cold fluid, would pass the control orifice with the least resistance. The relative internal orifices control the fluid capacity of the fuse, balancing the amount of fluid necessary to bottom the piston against the volumetric capacity of the fuse. The above mentioned warm reserve of fluid in cavity "A" is of sufficient quantity to start the piston in a closing direction prior to passage of an equivalent percent of the volumetric capacity through the relative orifices in the sleeve of the fuse. This would result in the fuse closing prior to reaching its rated capacity.

The results tabulated on Table IX Pages 23 and 24 are those obtained when a 12 ft. length of line was placed upstream, between the fuse and the transfer cylinder, as shown on Figure 4. This length of line is sufficient to correct the viscosity differential mentioned above, resulting in a satisfactory value of volumetric capacity.

Conclusions: The subject valves will comply with Paragraph 4.5.6(c) of Specification MIL-F-5508, providing sufficient warm-up distance is allowed between the fuse and fluid reservoir or other large quantity of oil. It is recommended that there be a minimum fluid path of 12 ft, upstream between the fuse and the oil reservoir, or the substitution of a fuse of at least 130% of the required capacity whenever the condition outlined in the above mentioned para-graph 4.5.6(c) can be realized.

TABLE VIII

Extreme Temperature Test Results (Rapid Warm-Up)

Fuse # 16667 Volumetric Capacity 80 in^3

Volumetric Capacity Test

Volume in^3	Time min	Flow GPM	Fluid Temperature °F	Room Temperature °F
88	0	2.5	-68	-68
45	15	2.5	-51	+76
39	30	2.5	-36	+76
44	40	2.5	-20	+76
55	50	2.5	-11	+76
72	60	2.5	- 2	+76
68	70	2.5	+ 9	+76
71	80	2.5	+17	+76
74	90	2.5	+20	+76
79	100	2.5	+25	+76
81	110	2.5	+31	+76
83	120	2.5	+36	+76
85	135	2.5	+44	+76
88	150	2.5	+59	+76

Fuse # 16661 Volumetric Capacity 20 in^3

Volumetric Capacity Test

Volume in^3	Time min	Flow GPM	Fluid Temperature °F	Room Temperature °F
24	0	2.5	-68	-68
18	15	2.5	-44	+76
15	30	2.5	-20	+76
16	45	2.5	- 8	+76
16	60	2.5	+ 4	+76
18	75	2.5	+14	+76
19	90	2.5	+22	+76
19	105	2.5	+28	+76
20	120	2.5	+33	+76
22	135	2.5	+40	+76
24	150	2.5	+52	+76

TABLE VIII (CONTINUED)

Fuse # 16674 Volumetric Capacity 120 in^3

Volumetric Capacity Test

Volume in^3	Time min	Flow GPM	Fluid Temperature °F	Room Temperature °F
162	5	5.27	-28	-78
118	7	7.68	-23	+78
121	10	7.92	-18	+78
116	20	3.00	- 4	+78
114	25	2.96	+ 5	+78
108	30	2.83	+11	+78
114	35	2.96	+13	+78
118	40	2.97	+18	+78
122	45	3.08	+22	+78
124	55	3.15	+28	+78
124	60	3.5	+30	+78
128	75	2.77	+42	+78
135	90	2.80	+54	+78

TABLE IX

Extreme Temperature Test Results (Rapid Warm-Up)
Using 12 ft Length of Line Preceding Fuse

Fuse # 16691 Volumetric Capacity in^3
Volumetric Capacity Test

Volume in^3	Time Elapsed minutes	Time of Cycle Sec	Temp of Fluid °F	Room Temp °F
11.6	5	1	-30	+70
13.4	5	7	-30	+70
11.6	10	1	-20	+70
11.8	10	5	-20	+70
11.6	15	1	+ 5	+70
11.8	15	5	+ 5	+70
11.3	15	1/2	+ 5	+70
11.0	20	1/2	+25	+70
11.3	20	1	+25	+70
11.3	20	4	+25	+70
10.7	30	1/2	+50	+70
10.7	30	1	+50	+70
11.0	30	5	+50	+70
10.7	50	1/2	+70	+70
10.7	50	1/2	+70	+70
10.8	50	5	+70	+70

Fuse # 67671 Volumetric Capacity 20 in^3
Volumetric Capacity Test

Volume in^3	Time Elapsed minutes	Time of Cycle Sec	Temp of Fluid °F	Room Temp °F
20.7	3	2	+10	+70
20.7	5	2	0	+70
19.5	5	5	0	+70
21.7	8	2	+15	+70
20.7	8	5	+15	+70
20.4	10	5	+20	+70
21.7	15	2	+30	+70
20.1	15	5	+30	+70
22.9	22	2	+40	+70
20.7	22	6	+40	+70
20.1	22	5	+40	+70
21.7	30	2	+50	+70
20.1	30	5	+50	+70
22.5	42	3	+60	+70
20.7	42	5	+60	+70
22.5	60	2	+70	+70
20.7	60	5	+70	+70

TABLE IX (CONTINUED)

Fuse # 53300 Volumetric Capacity 60 in^3
Volumetric Capacity Test

Volume in^3	Time Elapsed minutes	Time of Cycle Sec	Temp of Fluid °F	Room Temp °F
63	4	3	-35	+70
63	5	3	-35	+70
65	6	3	-35	+70
60	10	4	-25	+70
68	11	4	-25	+70
59	15	4	-15	+70
72	16	3	-15	+70
70	16	2	-15	+70
68	17	2	-15	+70
63	20	3	- 8	+70
65	21	3	- 8	+70
65	27	3	- 0	+70
64	27	3	- 0	+70
65	28	3	- 0	+70
66	35	4	+10	+70
66	35	3	+10	+70
65	35	3	+10	+70
66	50	3	+25	+70
66	50	3	+25	+70
66	51	3	+25	+70

Endurance Test

Test and Purpose: Paragraph 4.5.7, "Endurance". To determine the effect of repeated operation of fuse, on its operating characteristics.

Test Equipment: As shown by Figure 5 and Photograph 4.

Test Procedure: Fuse tested: Serial number 67671. With the set-up as shown in Figure 5, (oil pressure at 3000 psi), the fuse was operated 20,000 times at 6 gpm flow. The fuse was then operated for 100 additional cycles of full closing and resetting, the closing pressure being the rated pressure (3000 psi). Following the endurance cycling the fuse was tested for leakage and internal failure.

Test Results: The fuse # 67671 with a volumetric capacity of 20 in^3, satisfactorily completed 20,000 operational cycles plus 100 closing cycles at the above mentioned conditions. The fuse leakage, following this test, was within the permissable range.

Conclusion: The subject valve complies with the requirement of Paragraph 4.5.7 of Specification MIL-F-5508.

Acceleration Test

Test and Purpose: Paragraph 4.5.8, "Acceleration." To determine if operating characteristics of fuse are effected by an acceleration of 12 "gs".

Test Equipment: As shown by Figure 6.

Test Procedure: Fuses tested: Serial numbers 16661, and 16679. After the fuse had been operated a few times to make sure it was completely bled, it was whirled at a speed necessary to produce 12 "gs", in the direction of closing. This acceleration was maintained for several seconds and the fuse operated at a flow of 6 gpm while whirling. The fuse was then reversed and the above operation repeated with the acceleration tending to open the fuse.

Test Results: Fuse # 16661 Volumetric Capacity 20 in^3 acceleration tending to close the fuse:

Flow GPM	Volumetric Capacity in^3	Acceleration "gs"
6	23	12

Acceleration tending to open the fuse

Pressure in PSI	Leakage drops/minute	Acceleration "gs"
40	0	12

Fuse # 16670 Volumetric Capacity 160 in^3
Acceleration tending to close the fuse

Flow GPM	Volumetric Capacity in^3	Acceleration "gs"
6	174	12

Acceleration tending to open the fuse

Pressure PSI	Leakage drops/minute	Acceleration "gs"
40	0	12

Conclusion: The subject valve complies with Paragraph 4.5.8 of Specification MIL-F-5508.

Bleeding Test

Test and Procedure: Paragraph 4.5.9, "Bleeding". To determine the volumetric capacity of a fuse when installed in a hydraulic system and operated with no initial fluid in it.

Test Equipment: As shown by Figure 7.

Test Procedure: Fuses tested: Serial numbers 16661, and 16679. The fuse, completely emptied of fluid, was installed and operated at 6 gpm fluid flow.

Test Results: Fuse # 16661, Volumetric capacity 20 in^3, passed 22 in^3. Fuse # 16679, volumetric capacity 160 in^3, passed 168 in^3.

Conclusion: The subject valve complies with Paragraph 4.5.9 of Specification MIL-F-5508.

Resetting Test

Test and Purpose: Paragraph 4.5.10, "Resetting". To determine the capability of the fuse to reset within 5 seconds, without the aid of reverse flow, after the pressure has been equalized to 3000 psi on each side.

Test Equipment: As shown by Figure 8.

Test Procedure: Fuses Tested: Serial numbers 16661, and 16679. With the set-up as shown in Figure 8 the fuse was operated at a fluid flow of 6 gpm. After closing, the directional control valve was operated to equalize the pressure on both sides of the fuse and then returned to the original position in 5 seconds or less.

Test Results: Fuse # 16661, volumetric capacity of 20 in^3, passed 23 in^3 and fused in less than 5 seconds. Fuse # 16679, having a volumetric capacity of 160 in^3, passed 172 in^3 and fused in less than 5 seconds.

Conclusion: The subject valve complies with Paragraph 4.5.10 of Specification MIL-F-5508.

Burst Pressure Test

Test and Purpose: Paragraph 4.5.11 "Burst Pressure". To determine the ability of the fuse to withstand a static hydraulic pressure of 2.5 times rated pressure (7500 psi), without rupture.

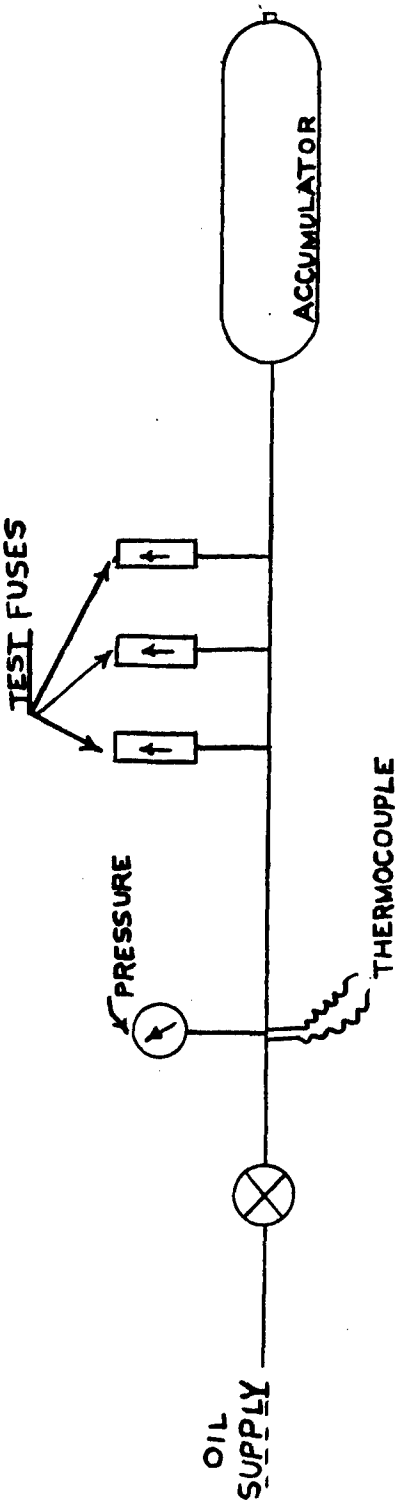
Test Procedure: Fuse Tested: Serial number 67671. Hydraulic pressure 7500 psi was applied to the valve and held for 5 minutes.

Test Results: There was no evidence of external leakage or failure of the fuse during the applied pressure.

Conclusion: The subject valve complies with Paragraph 4.5.11 of Specification MIL-F-5508.

FIG. 1

LEAKAGE TEST SET UP
PARAGRAPH 4.5.3
SPECIFICATION MIL-F-5508



VOLUMETRIC CAPACITY TEST

PARAGRAPH - 4.5.4

SPECIFICATION MIL-F-5508

FIG. 2

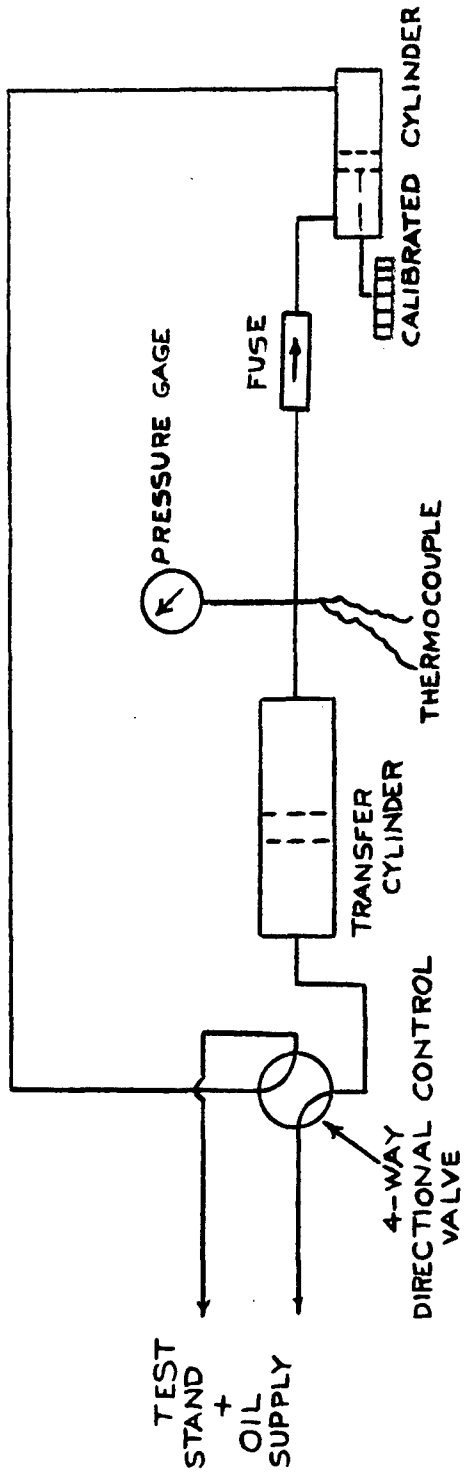


FIG. 3

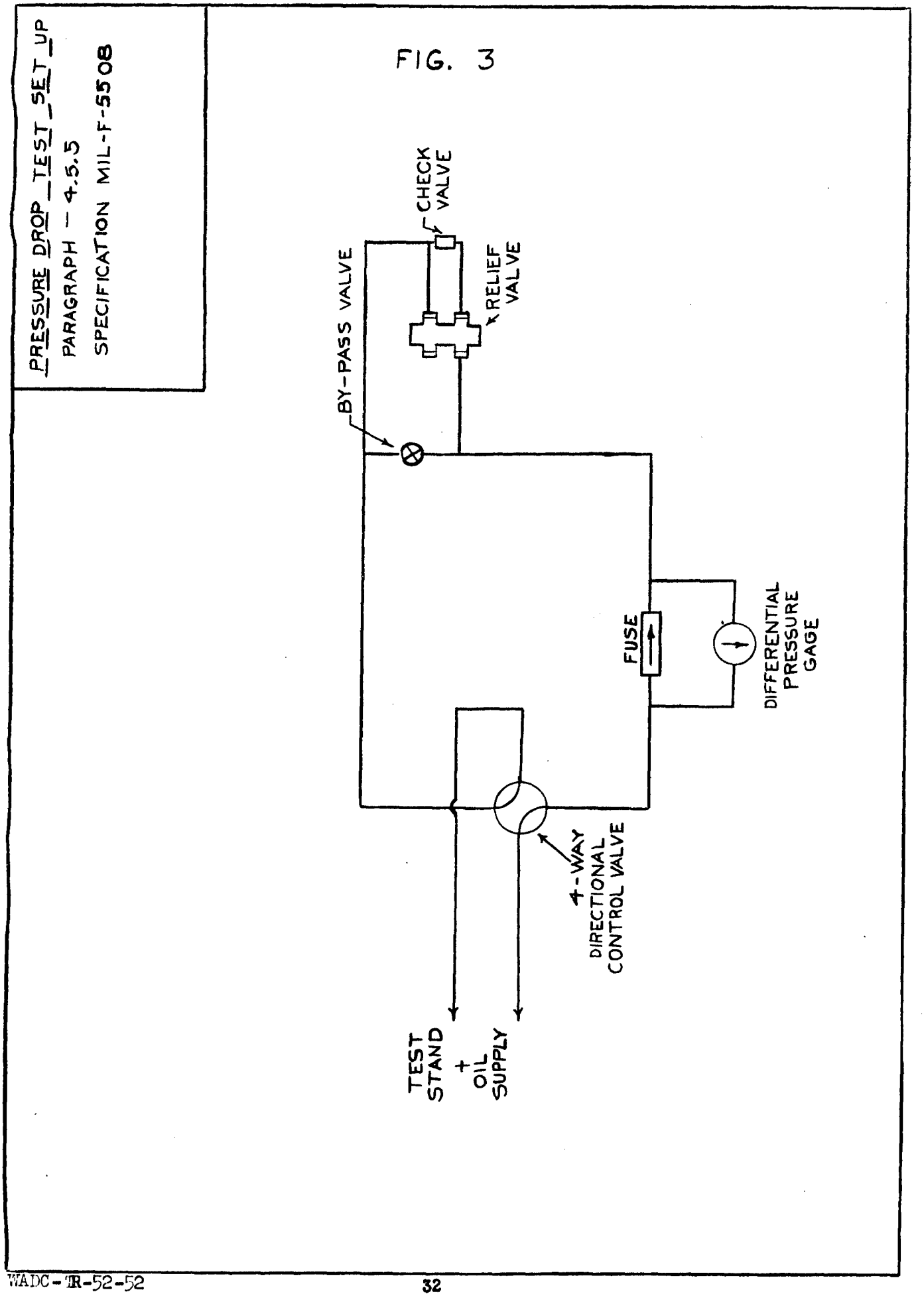

PRESSURE DROP TEST SET UP
PARAGRAPH - 4.5.5
SPECIFICATION MIL-F-5508
CHECK VALVE
RELIEF VALVE
BY-PASS VALVE
FUSE
DIFFERENTIAL PRESSURE GAGE
4-WAY DIRECTIONAL CONTROL VALVE
TEST STAND + OIL SUPPLY

FIG. 4

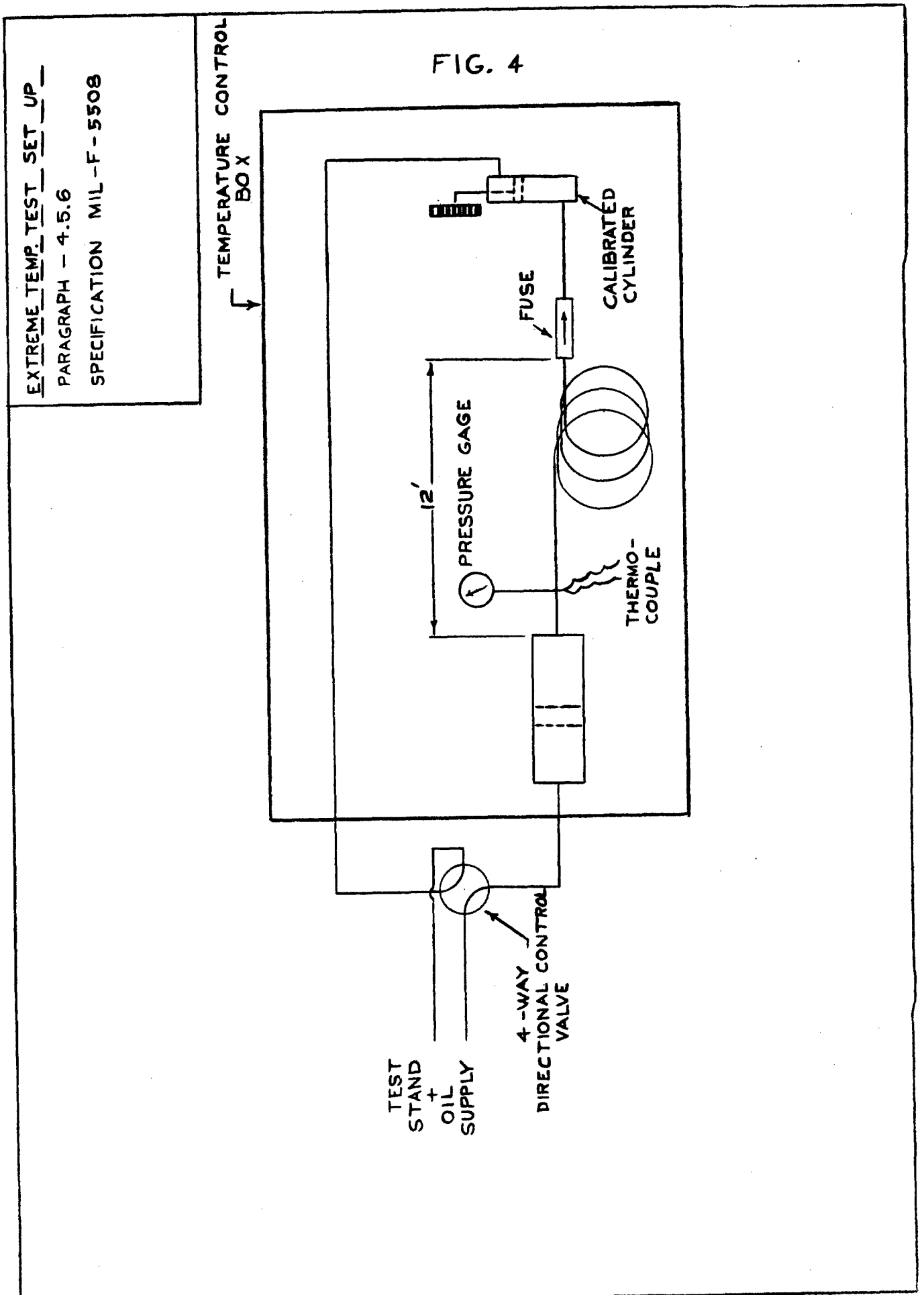
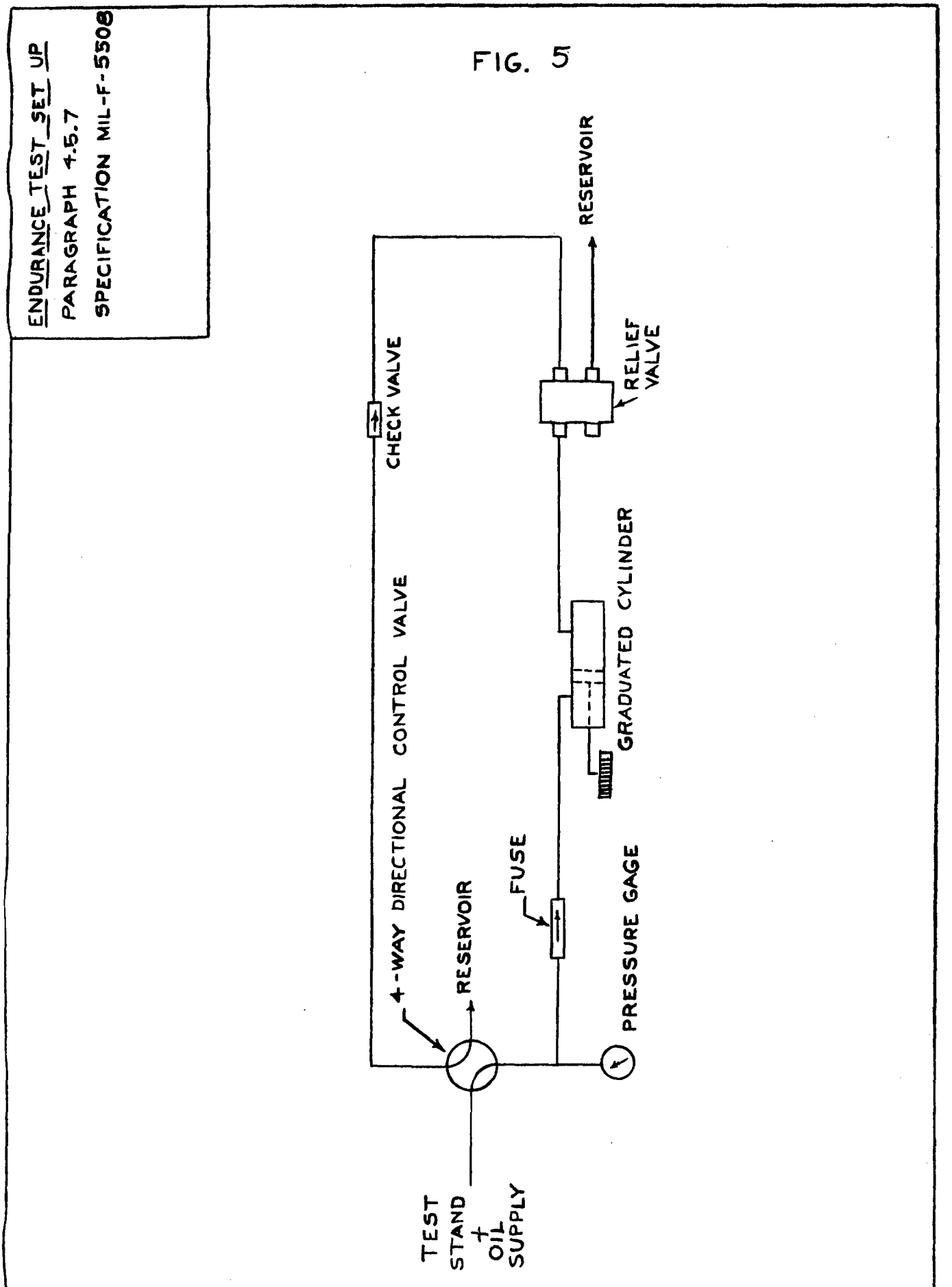

EXTREME TEMP. TEST SET UP
PARAGRAPH – 4.5.6
SPECIFICATION MIL-F-5508
TEMPERATURE CONTROL BOX
CALIBRATED CYLINDER
FUSE
12'
PRESSURE GAGE
THERMO-COUPLE
4-WAY DIRECTIONAL CONTROL VALVE
TEST STAND + OIL SUPPLY

FIG. 5


ENDURANCE TEST SET UP
PARAGRAPH 4.5.7
SPECIFICATION MIL-F-5508
RESERVOIR
CHECK VALVE
RELIEF VALVE
4-WAY DIRECTIONAL CONTROL VALVE
GRADUATED CYLINDER
RESERVOIR
FUSE
PRESSURE GAGE
TEST STAND + OIL SUPPLY

ACCELERATION TEST SET UP
PARAGRAPH - 4.5.8
SPECIFICATION - MIL-F-5508

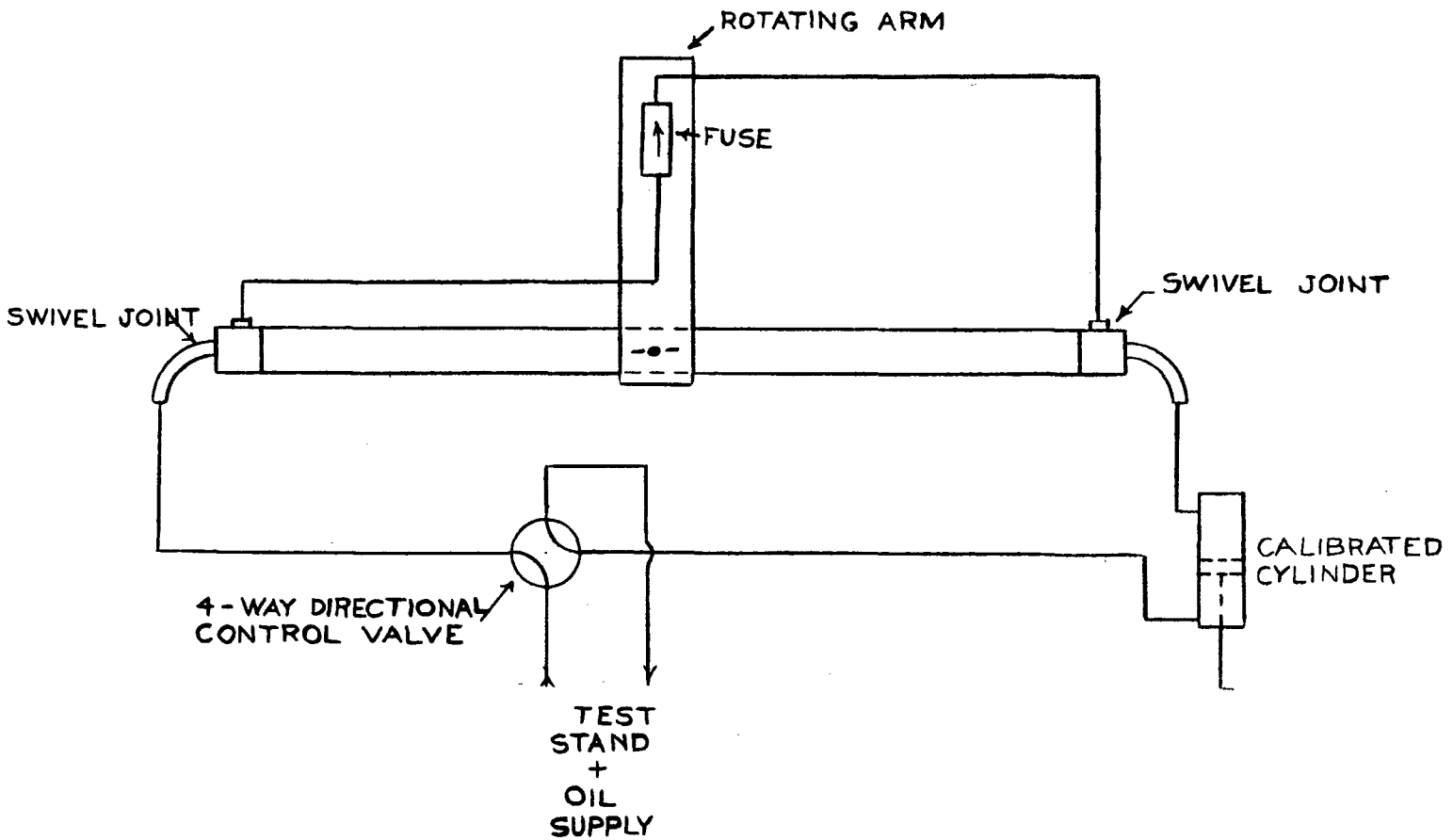
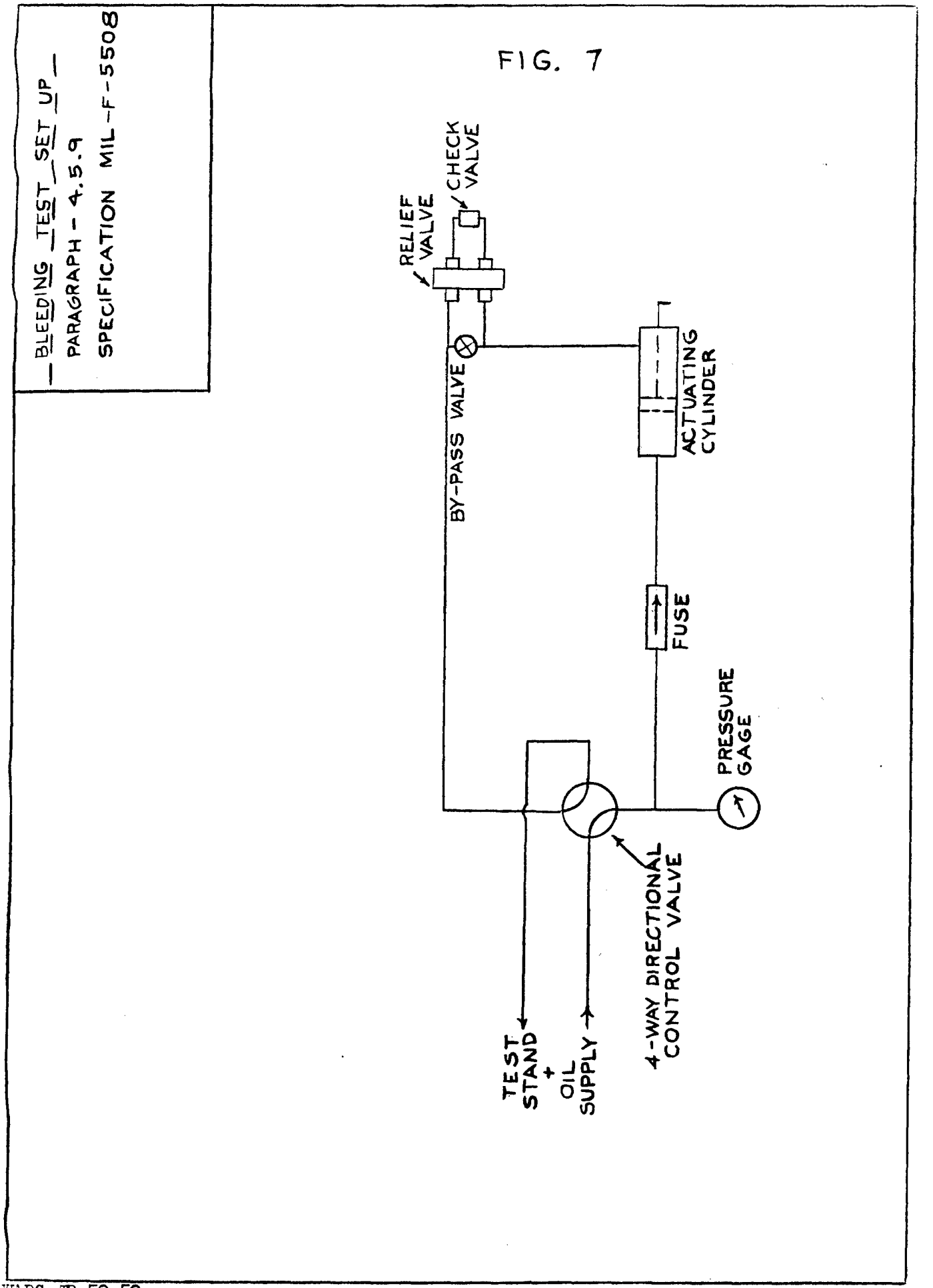


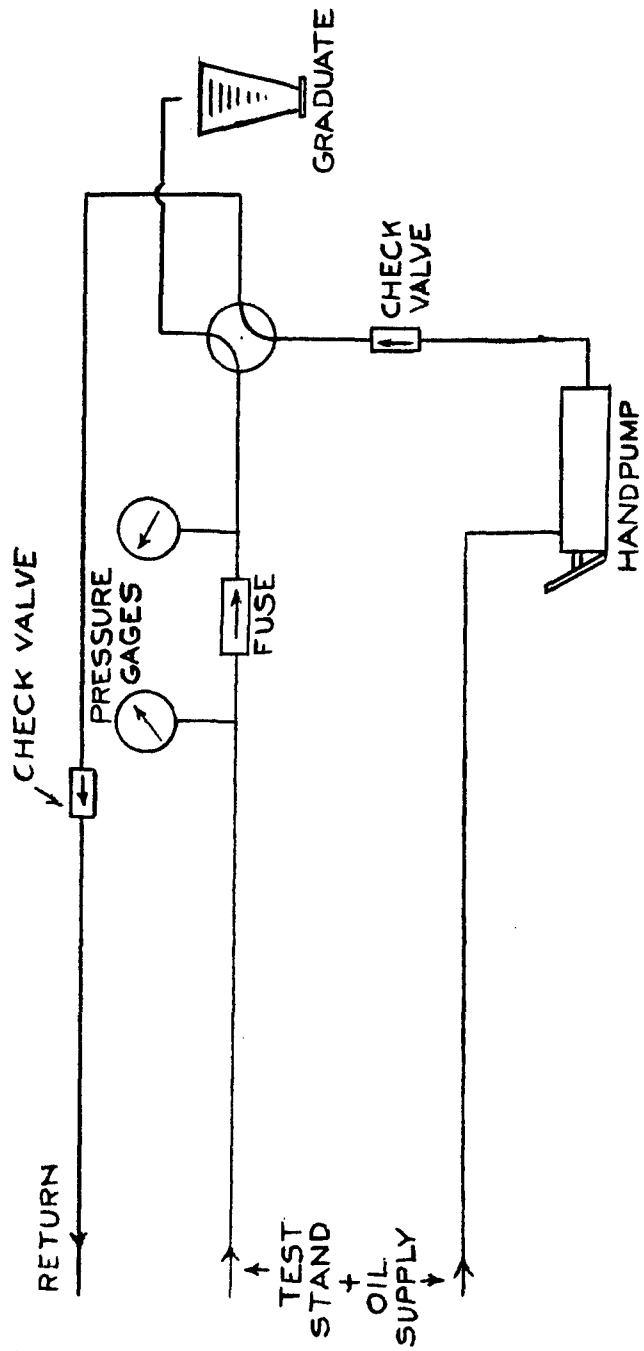
FIG. 6

FIG. 7


BLEEDING TEST SET UP
PARAGRAPH - 4.5.9
SPECIFICATION MIL-F-5508
RELIEF VALVE
CHECK VALVE
BY-PASS VALVE
ACTUATING CYLINDER
FUSE
PRESSURE GAGE
4-WAY DIRECTIONAL CONTROL VALVE
TEST STAND + OIL SUPPLY

RESET TEST SET UP
PARAGRAPH - 4.5.10
SPECIFICATION MIL-F-5508

FIG. 8



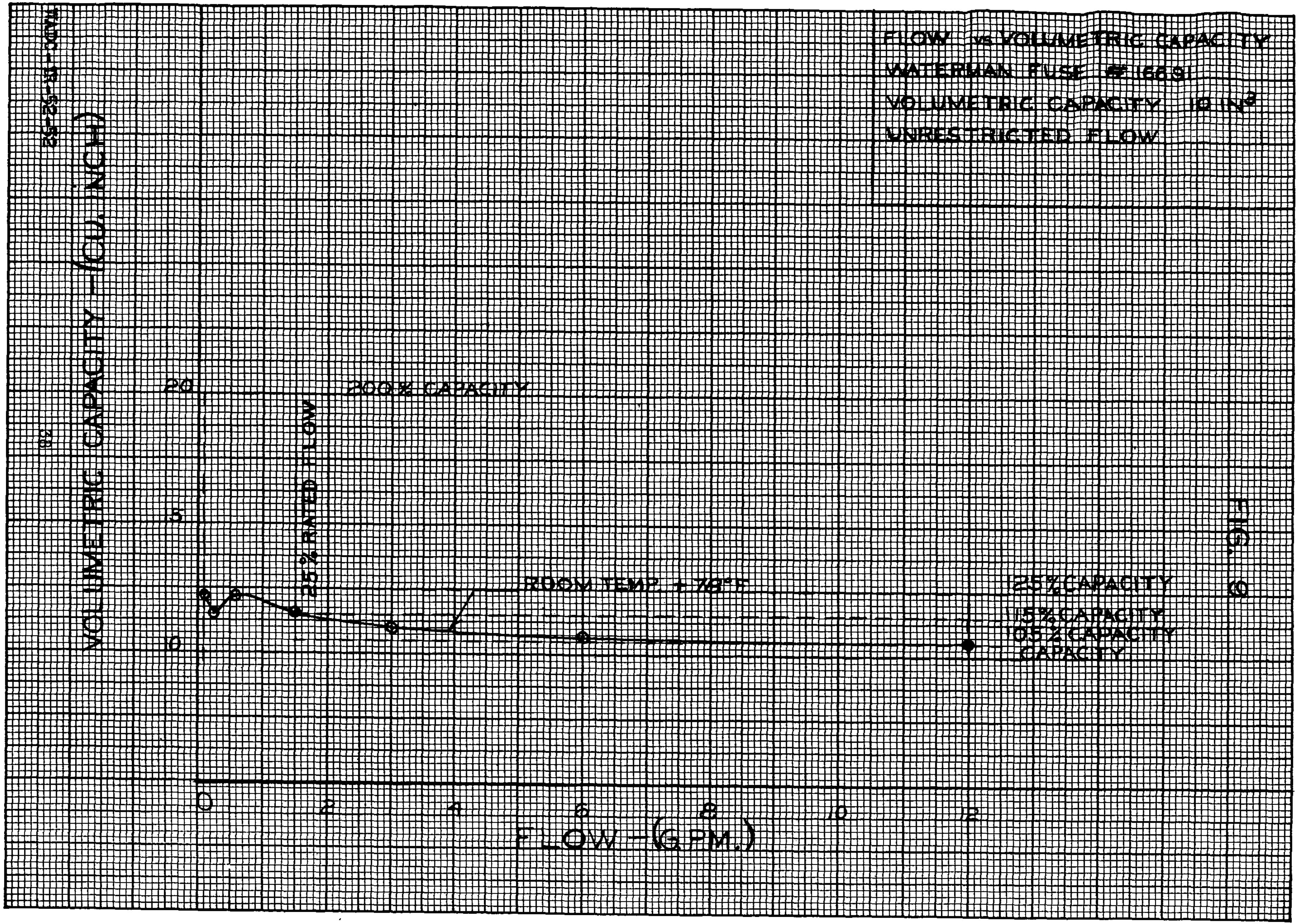

FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE #16691
VOLUMETRIC CAPACITY 10 IN³
UNRESTRICTED FLOW
200% CAPACITY
25% RATED FLOW
ROOM TEMP. + 78°F
125% CAPACITY
115% CAPACITY
105% CAPACITY
CAPACITY
VOLUMETRIC CAPACITY – (CU. INCH)
FLOW – (G.P.M.)
20
15
10
0
2
4
6
8
10
12

FIG. 9

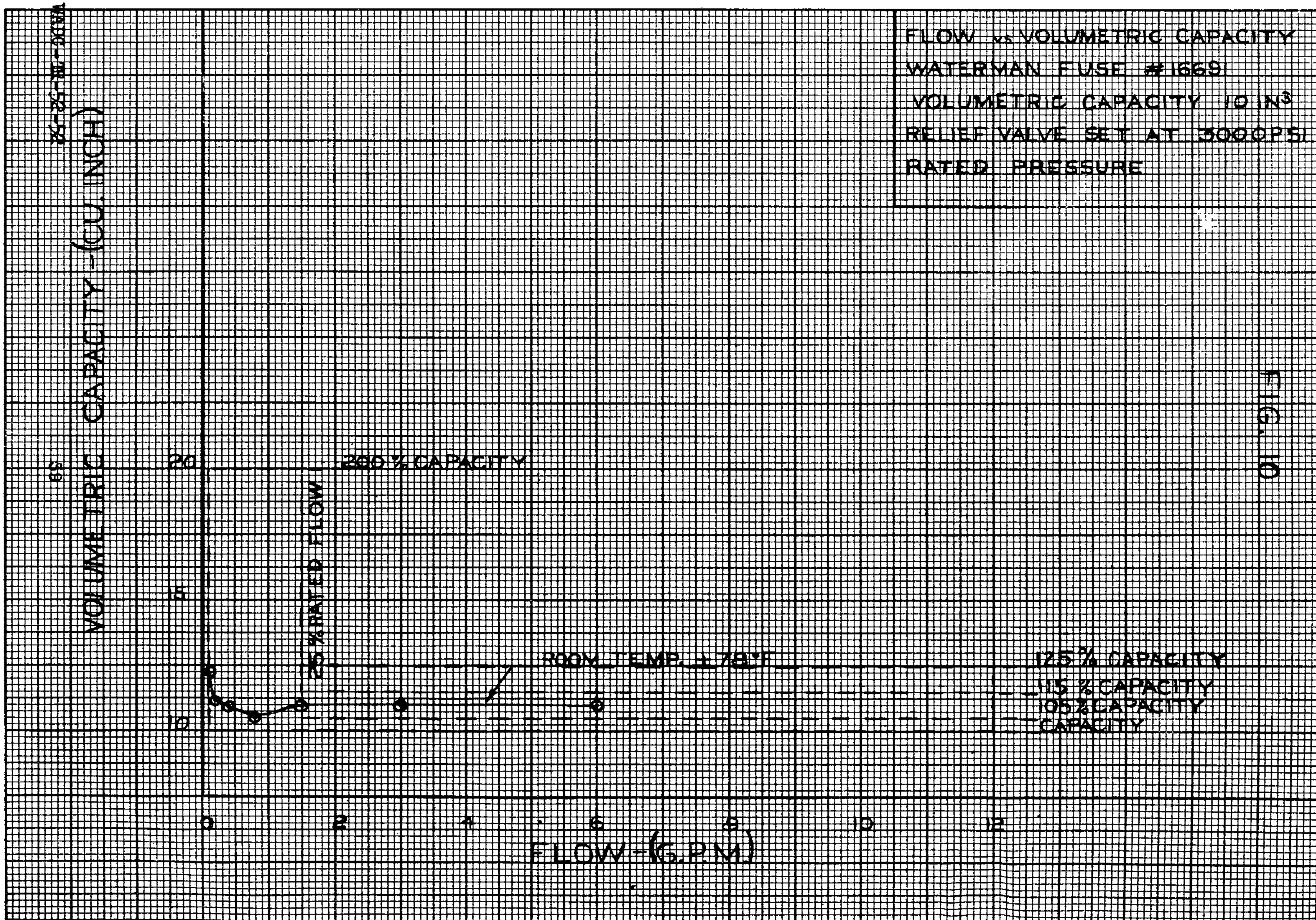

FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE #1669
VOLUMETRIC CAPACITY 10 IN³
RELIEF VALVE SET AT 3000 PSI
RATED PRESSURE
200 % CAPACITY
25 % RATED FLOW
ROOM TEMP. + 78°F
125 % CAPACITY
115 % CAPACITY
105 % CAPACITY
CAPACITY
VOLUMETRIC CAPACITY - (CU. INCH)
FLOW - (G.P.M.)
20
15
10
0
2
4
6
8
10
12

FIG. 10

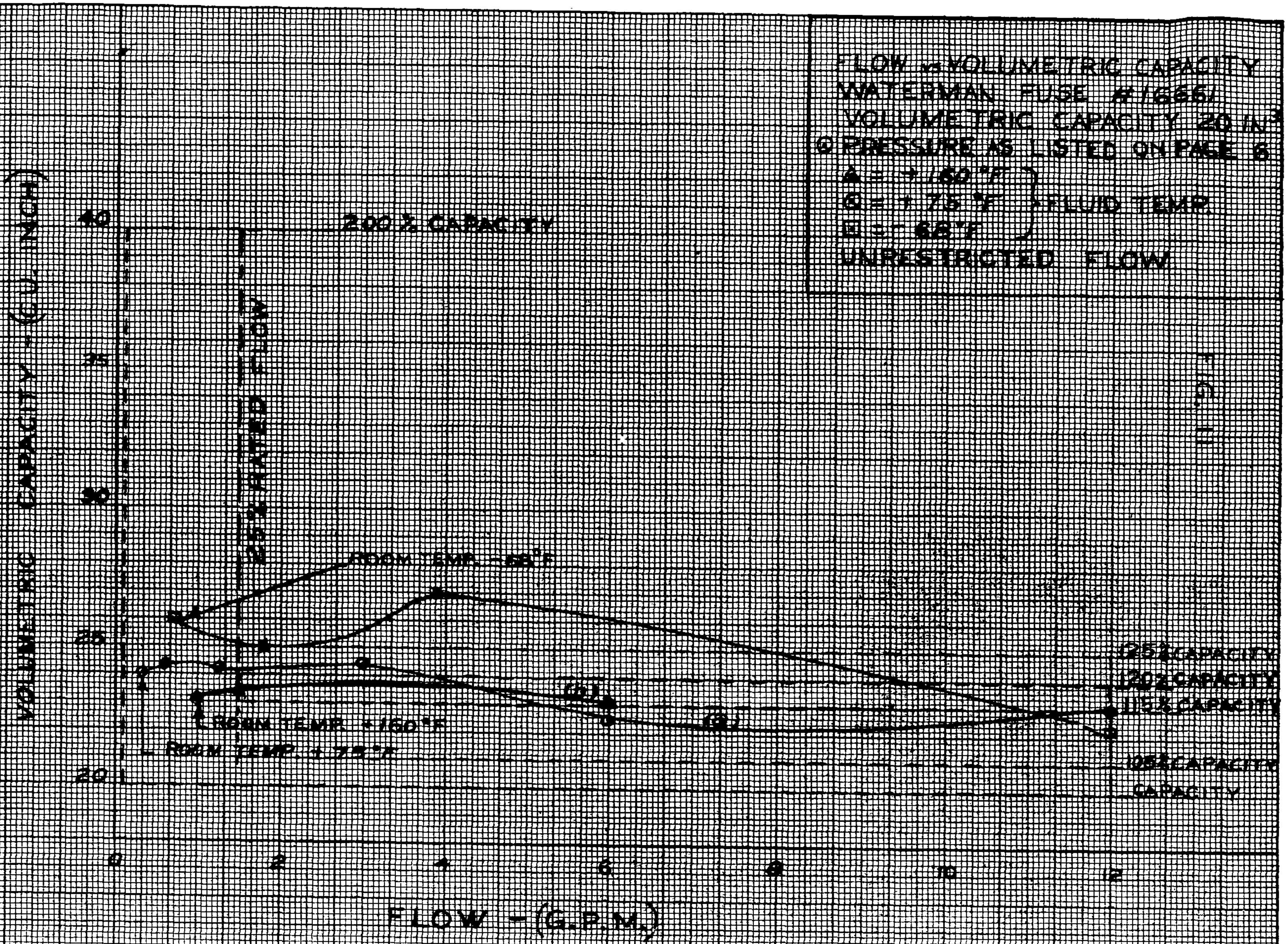

FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE #16661
VOLUMETRIC CAPACITY 20 IN³
@ PRESSURE AS LISTED ON PAGE 6
▲ = +160°F
⊙ = +75°F
⊡ = -68°F
FLUID TEMP.
UNRESTRICTED FLOW
200% CAPACITY
25% RATED FLOW
ROOM TEMP. -68°F
ROOM TEMP. +160°F
ROOM TEMP. +75°F
125% CAPACITY
120% CAPACITY
115% CAPACITY
105% CAPACITY
CAPACITY
VOLUMETRIC CAPACITY - (CU. INCH)
FLOW - (G.P.M.)
40
35
30
25
20
0
2
4
6
8
10
12

FIG. 11

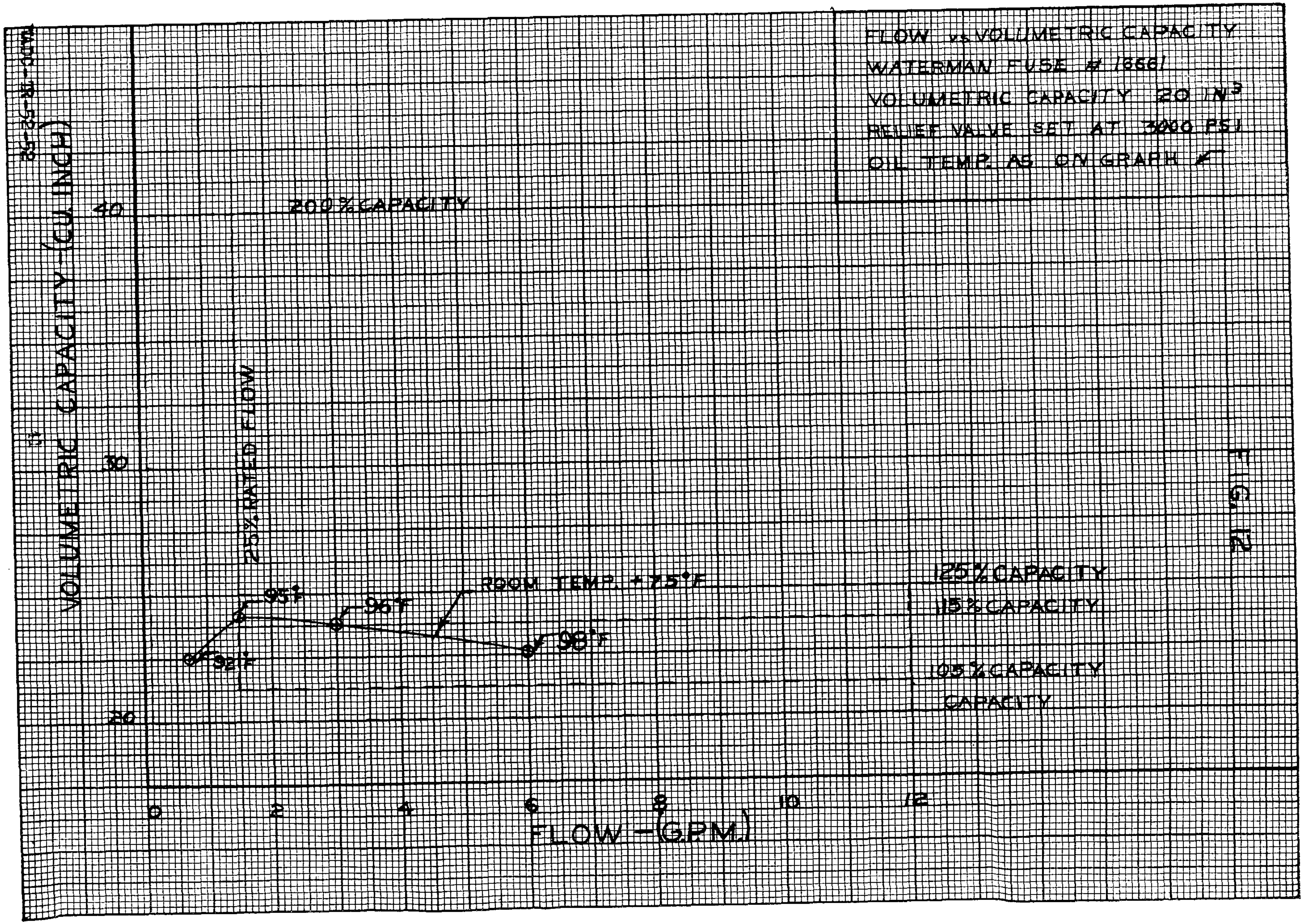
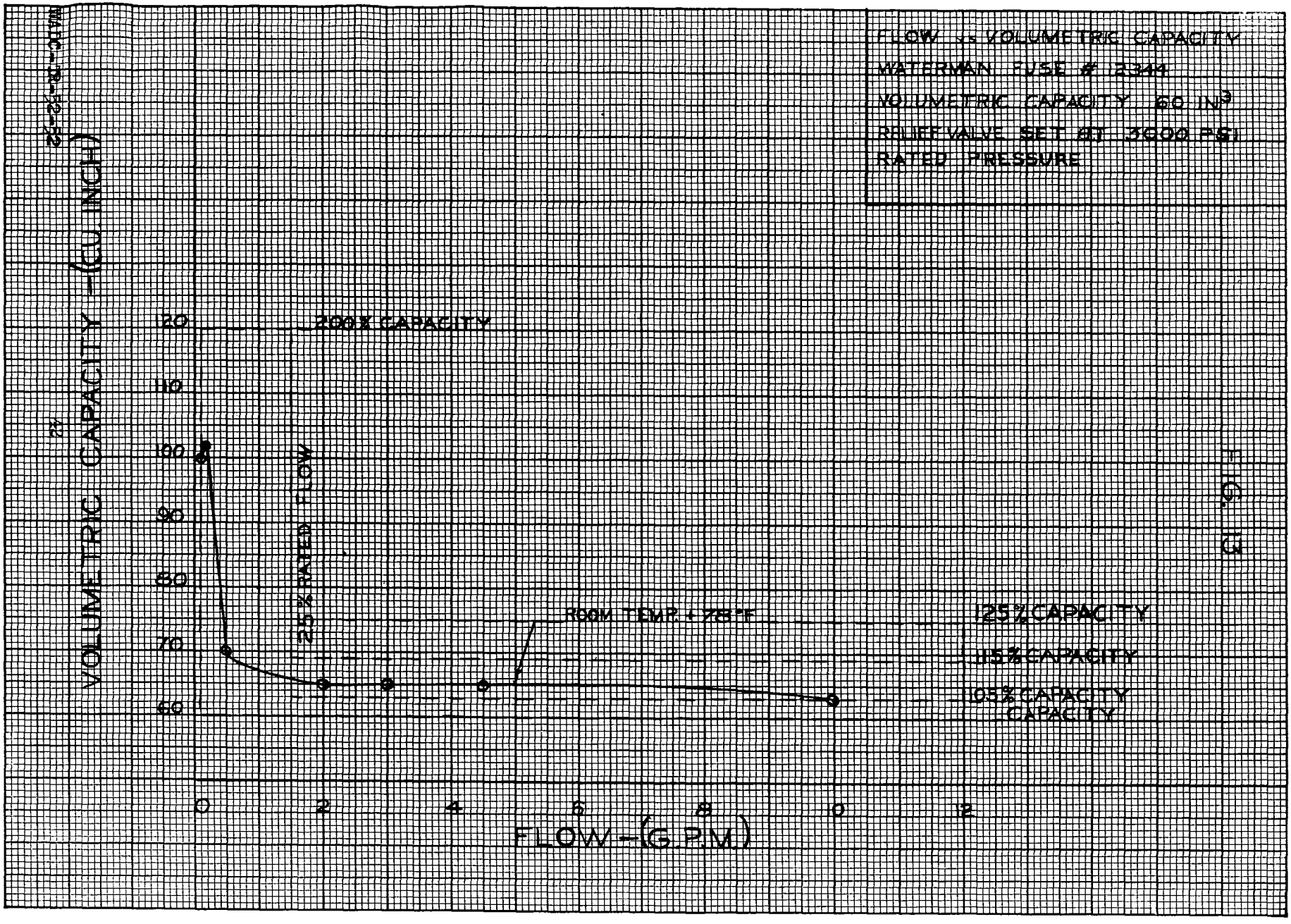
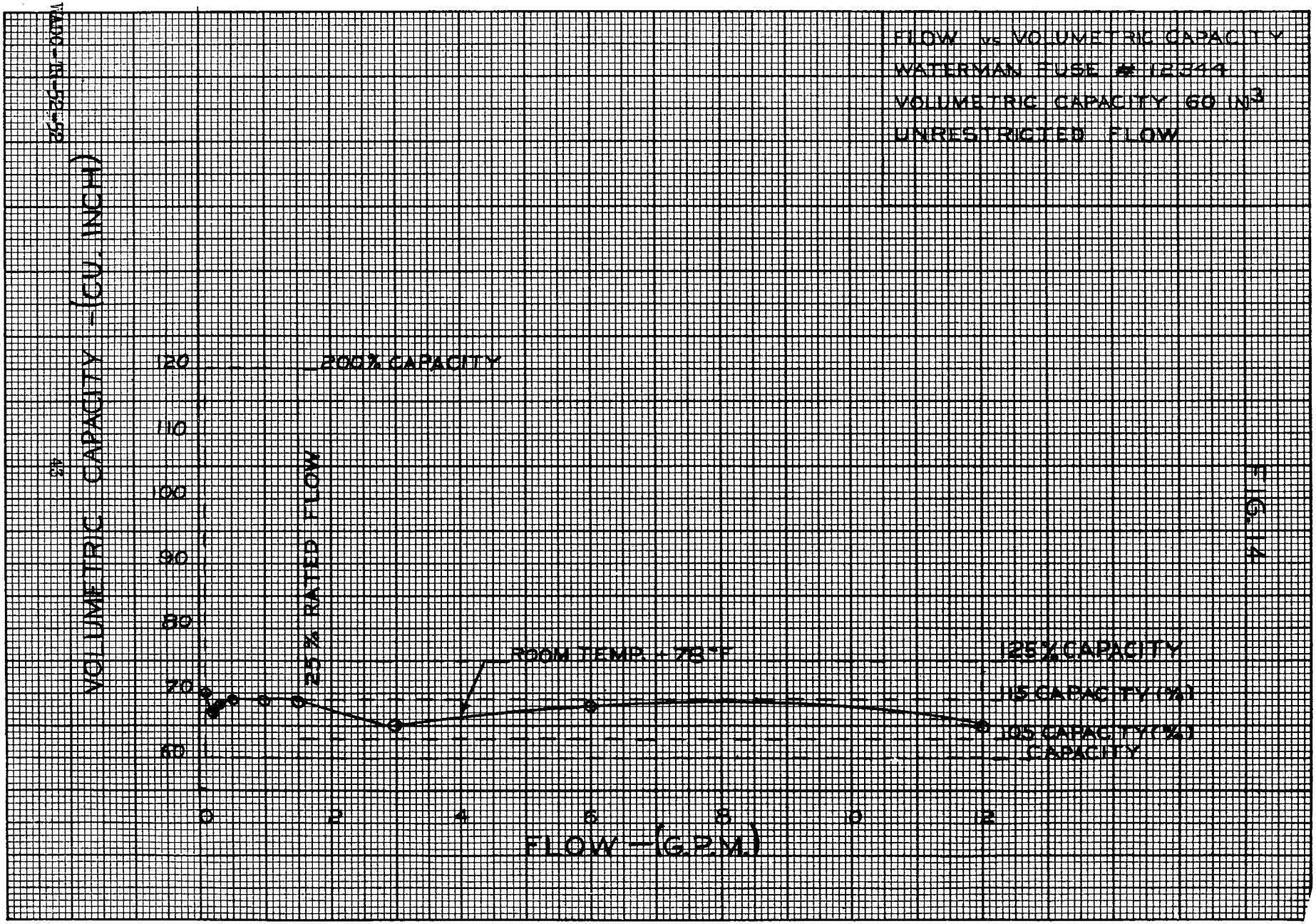

FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE # 16661
VOLUMETRIC CAPACITY 20 IN³
RELIEF VALVE SET AT 3000 PSI
OIL TEMP. AS ON GRAPH
200% CAPACITY
25% RATED FLOW
ROOM TEMP. +75°F
95°F
96°F
98°F
92°F
125% CAPACITY
115% CAPACITY
105% CAPACITY
CAPACITY
40
30
20
0
2
4
6
8
10
12
VOLUMETRIC CAPACITY -(CU. INCH)
FLOW -(G.P.M.)

FIG. 12


FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE # 2344
VOLUMETRIC CAPACITY 60 IN³
RELIEF VALVE SET AT 3000 PSI
RATED PRESSURE
VOLUMETRIC CAPACITY (CU. INCH)
200% CAPACITY
125% CAPACITY
115% CAPACITY
105% CAPACITY
CAPACITY
ROOM TEMP. + 78°F
FLOW - (G.P.M.)
120
110
100
90
80
70
60
0
2
4
6
8
10
12


FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE # 123444
VOLUMETRIC CAPACITY 60 IN³
UNRESTRICTED FLOW
VOLUMETRIC CAPACITY -(CU. INCH)
200% CAPACITY
120
110
100
90
80
70
60
RATED FLOW
ROOM TEMP. = 78°F
125% CAPACITY
115 CAPACITY (%)
105 CAPACITY (%)
CAPACITY
0
2
4
6
8
0
2
FLOW -(G.P.M.)

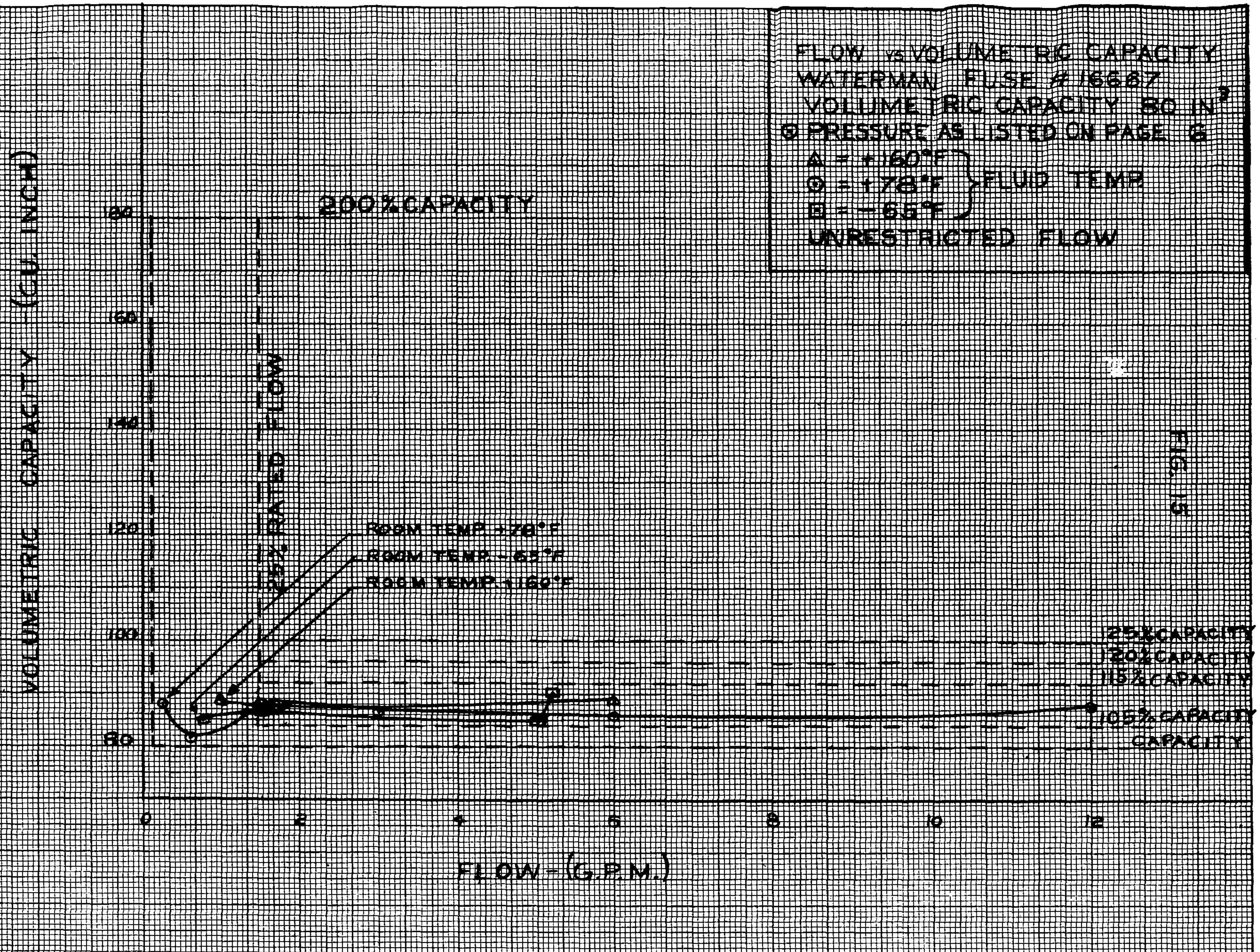

FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE # 16667
VOLUMETRIC CAPACITY 80 IN³
@ PRESSURE AS LISTED ON PAGE 6
△ = +160°F
⊙ = +78°F
⊡ = −65°F
FLUID TEMP
UNRESTRICTED FLOW
200% CAPACITY
25% RATED FLOW
ROOM TEMP. +78°F
ROOM TEMP. −65°F
ROOM TEMP. +160°F
125% CAPACITY
120% CAPACITY
115% CAPACITY
105% CAPACITY
CAPACITY
180
160
140
120
100
80
0
2
4
6
8
10
12
VOLUMETRIC CAPACITY − (CU. INCH)
FLOW − (G.P.M.)

FIG. 15

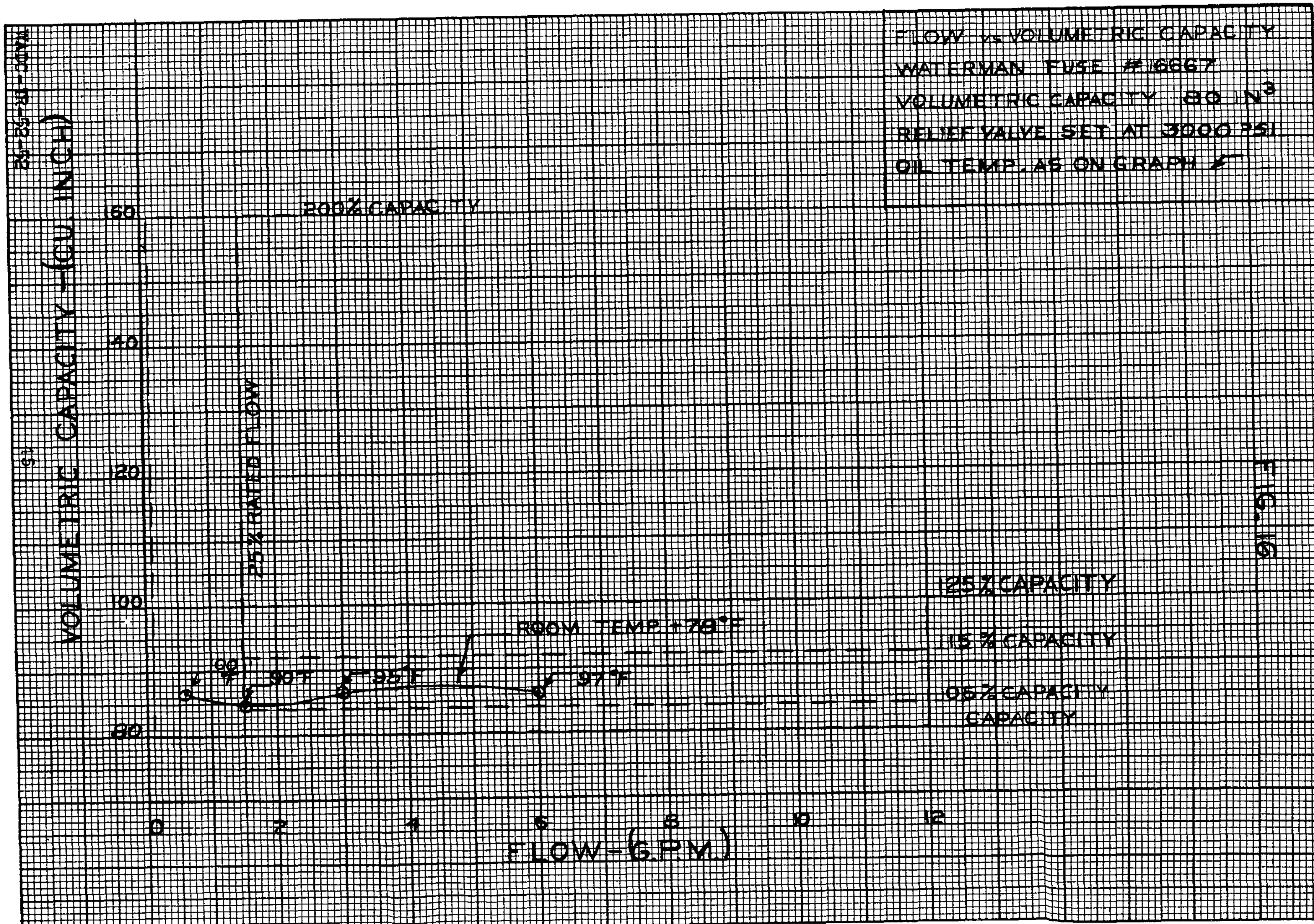
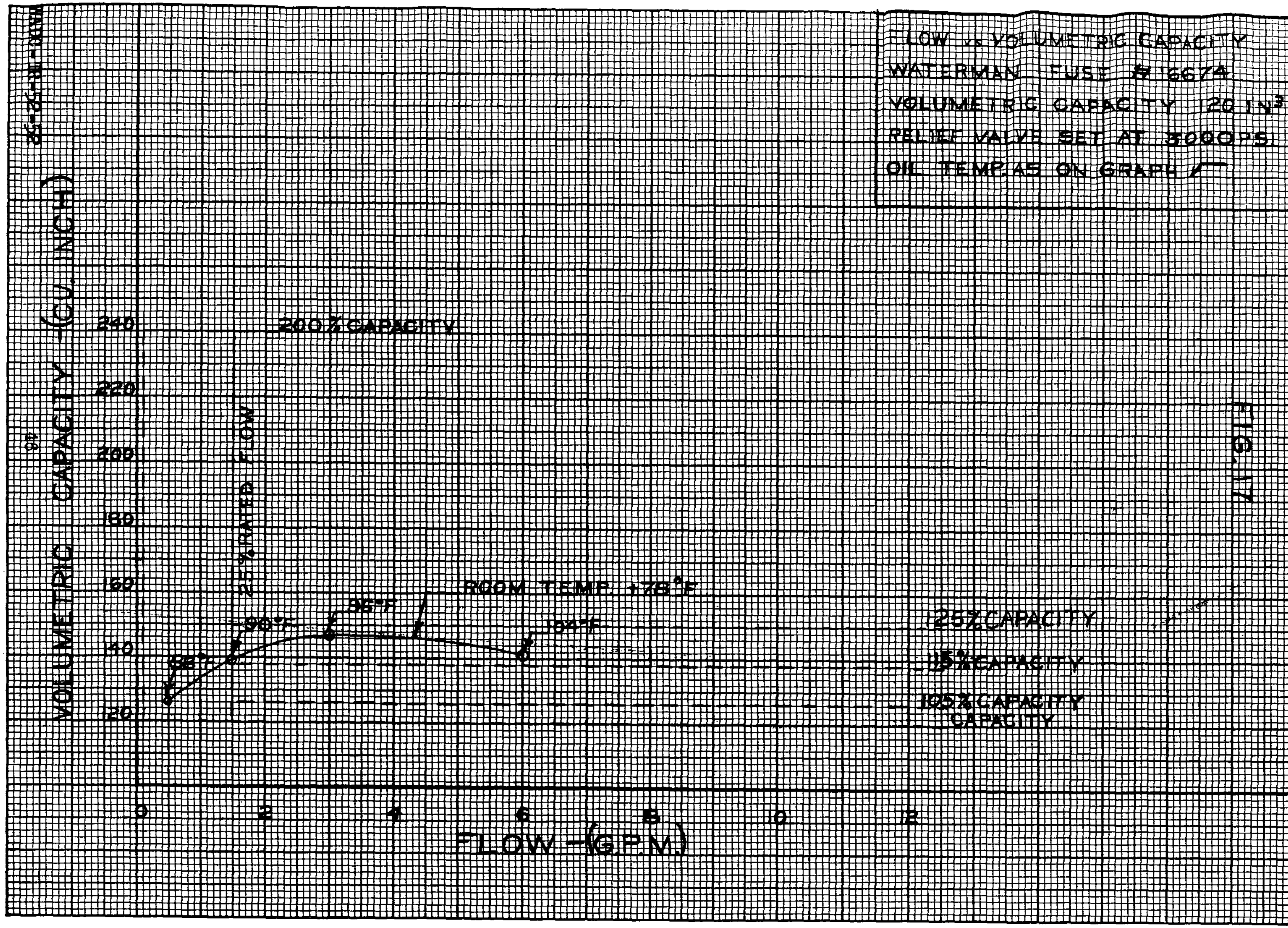
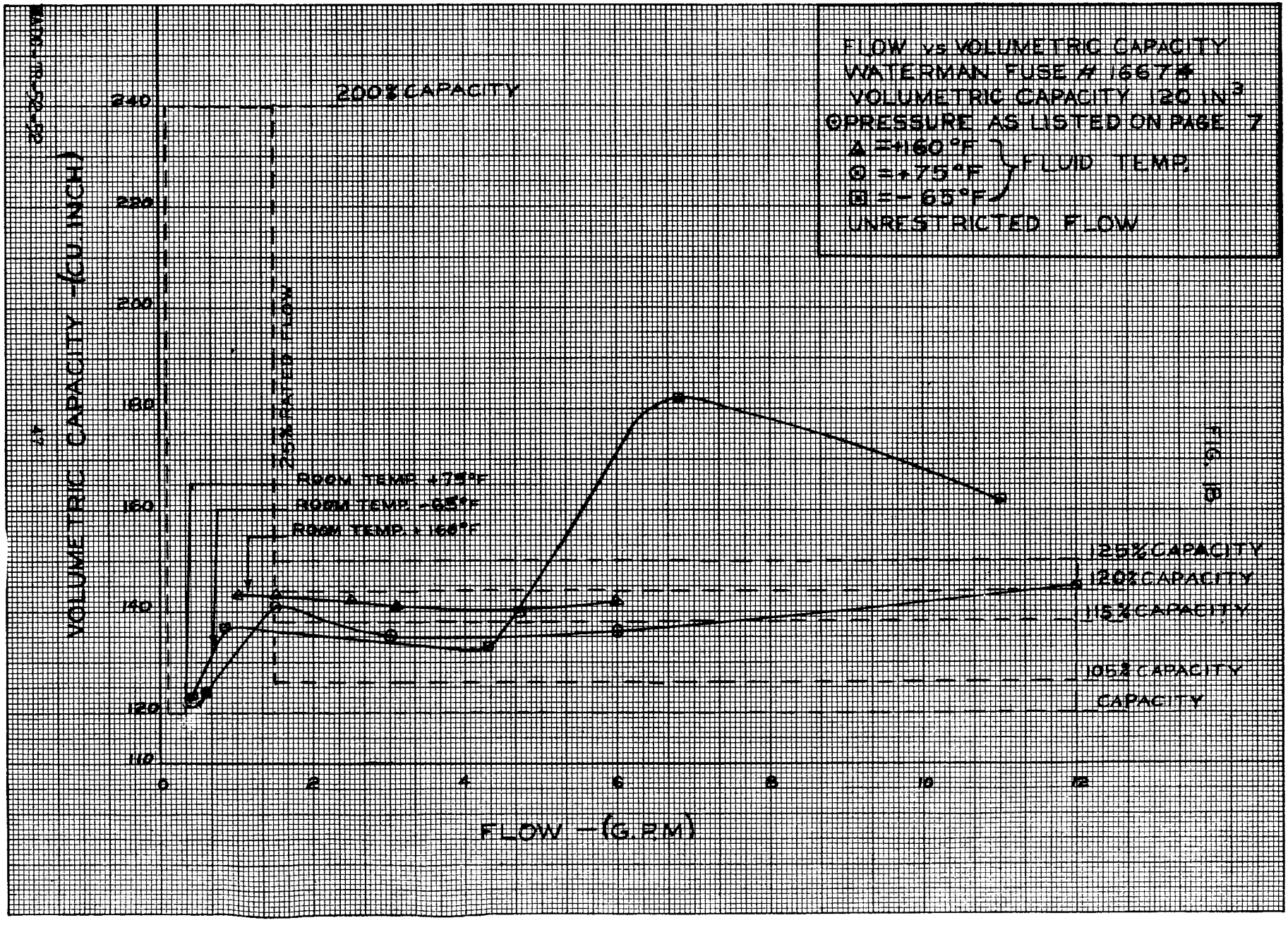

FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE #16667
VOLUMETRIC CAPACITY 80 IN³
RELIEF VALVE SET AT 3000 PSI
OIL TEMP. AS ON GRAPH
200% CAPACITY
25% RATED FLOW
125% CAPACITY
115% CAPACITY
105% CAPACITY
ROOM TEMP +78°F
90°F
90°F
95°F
97°F
160
140
120
100
80
0
2
4
6
8
10
12
VOLUMETRIC CAPACITY – (CU. INCH)
FLOW – (G.P.M.)

FIG. 16


FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE #16674
VOLUMETRIC CAPACITY 120 IN³
RELIEF VALVE SET AT 3000 PSI
OIL TEMP. AS ON GRAPH
FIG. 17
200% CAPACITY
25% RATED FLOW
ROOM TEMP. +78°F
88°F
90°F
95°F
104°F
125% CAPACITY
115% CAPACITY
105% CAPACITY
CAPACITY
VOLUMETRIC CAPACITY -(CU. INCH)
240
220
200
180
160
140
120
0
2
4
6
8
10
12
FLOW -(G.P.M.)


FLOW vs VOLUMETRIC CAPACITY
WATERMAN FUSE # 16674
VOLUMETRIC CAPACITY 120 IN³
@PRESSURE AS LISTED ON PAGE 7
Δ = +160°F
@ = +75°F
□ = −65°F
FLUID TEMP.
UNRESTRICTED FLOW
VOLUME CAPACITY (CU. INCH)
FLOW — (G.P.M.)
200% CAPACITY
125% CAPACITY
120% CAPACITY
115% CAPACITY
105% CAPACITY
CAPACITY
ROOM TEMP. +75°F
ROOM TEMP. −65°F
ROOM TEMP. +160°F
240
220
200
180
160
140
120
110
0
2
4
6
8
10
12

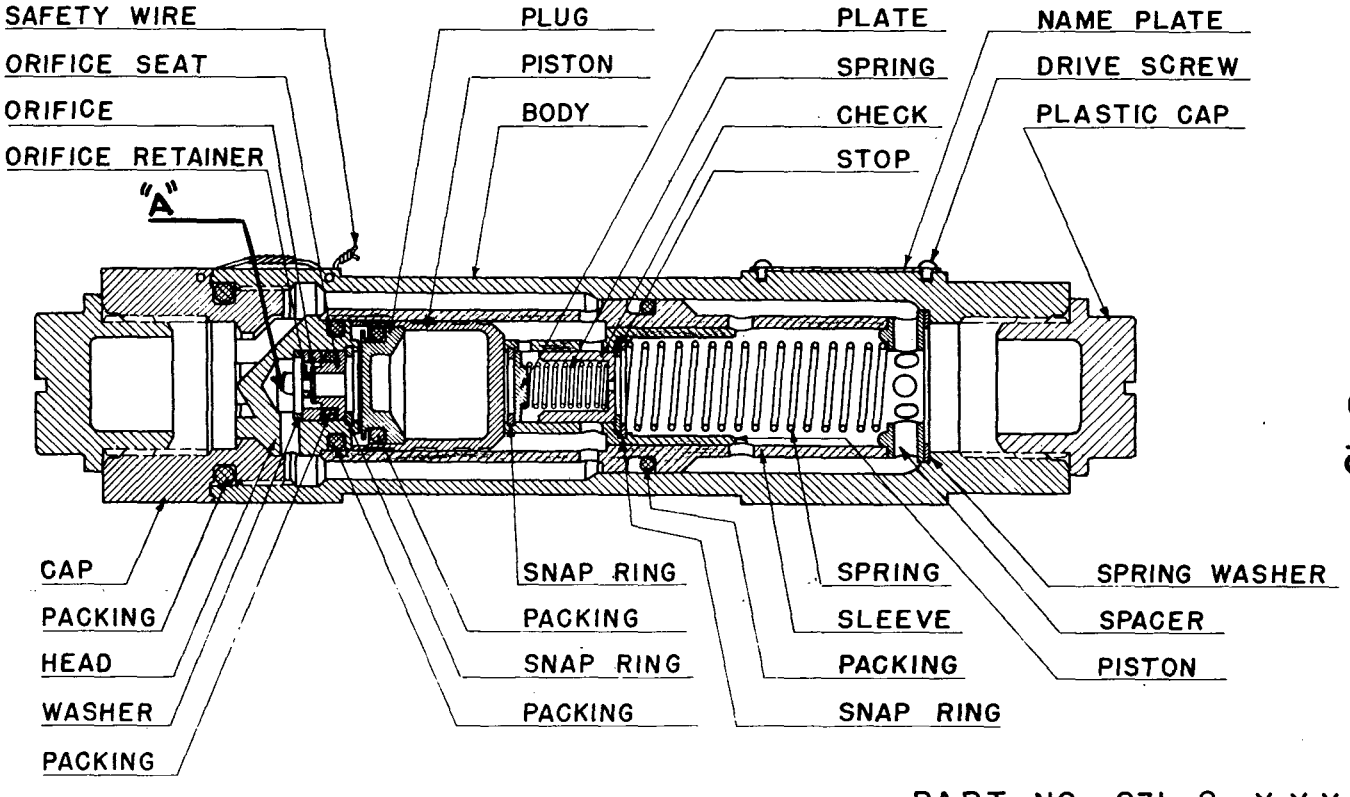


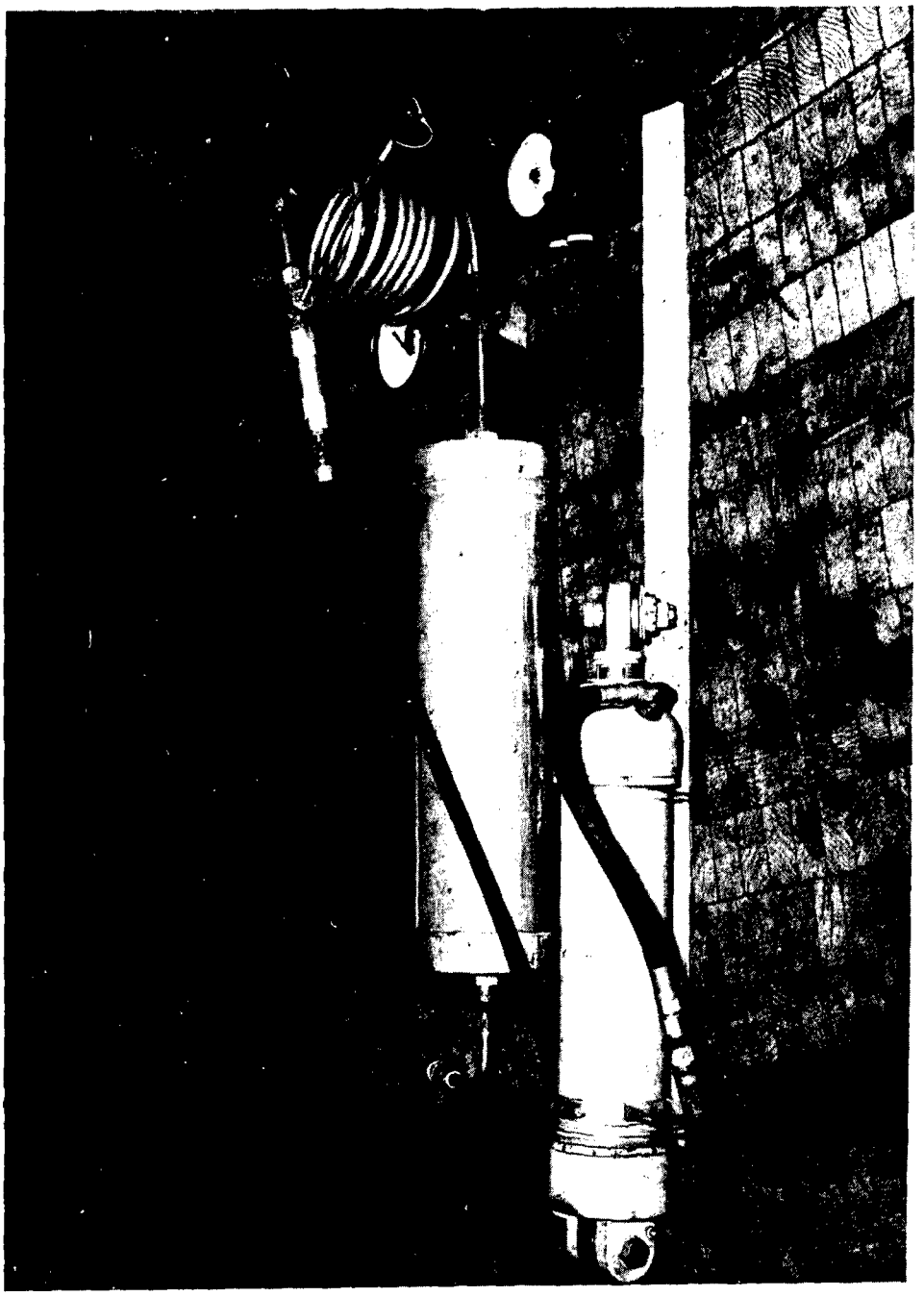
FIG. 19

PART NO. 831-8-XXX

THIS DRAWING IS FOR ILLUSTRATIVE PURPOSES ONLY

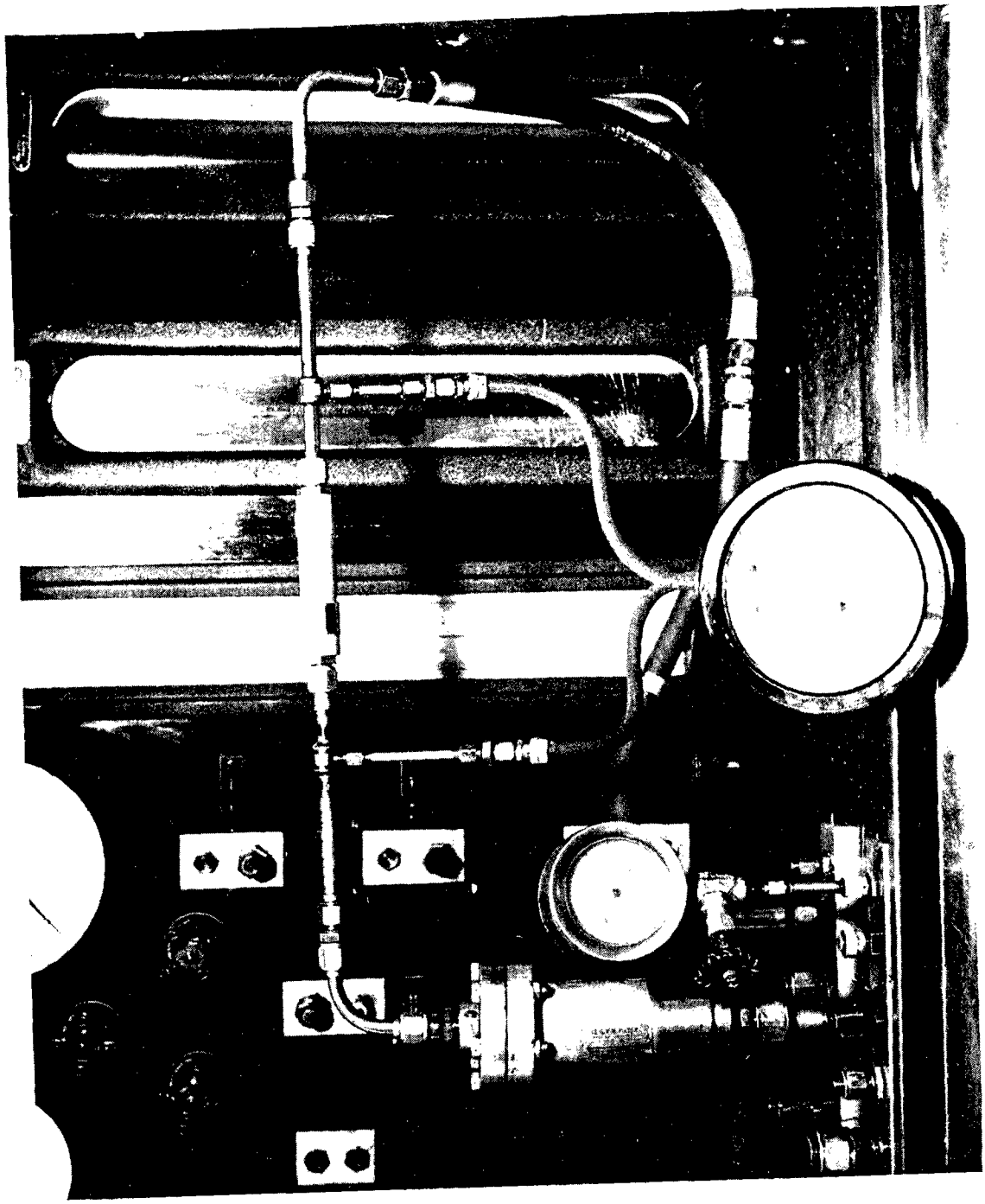
HYDRAULIC FUSE--QUANTITY MEASURING TYPE

Photograph I
Equipment used for "Leakage Tests"



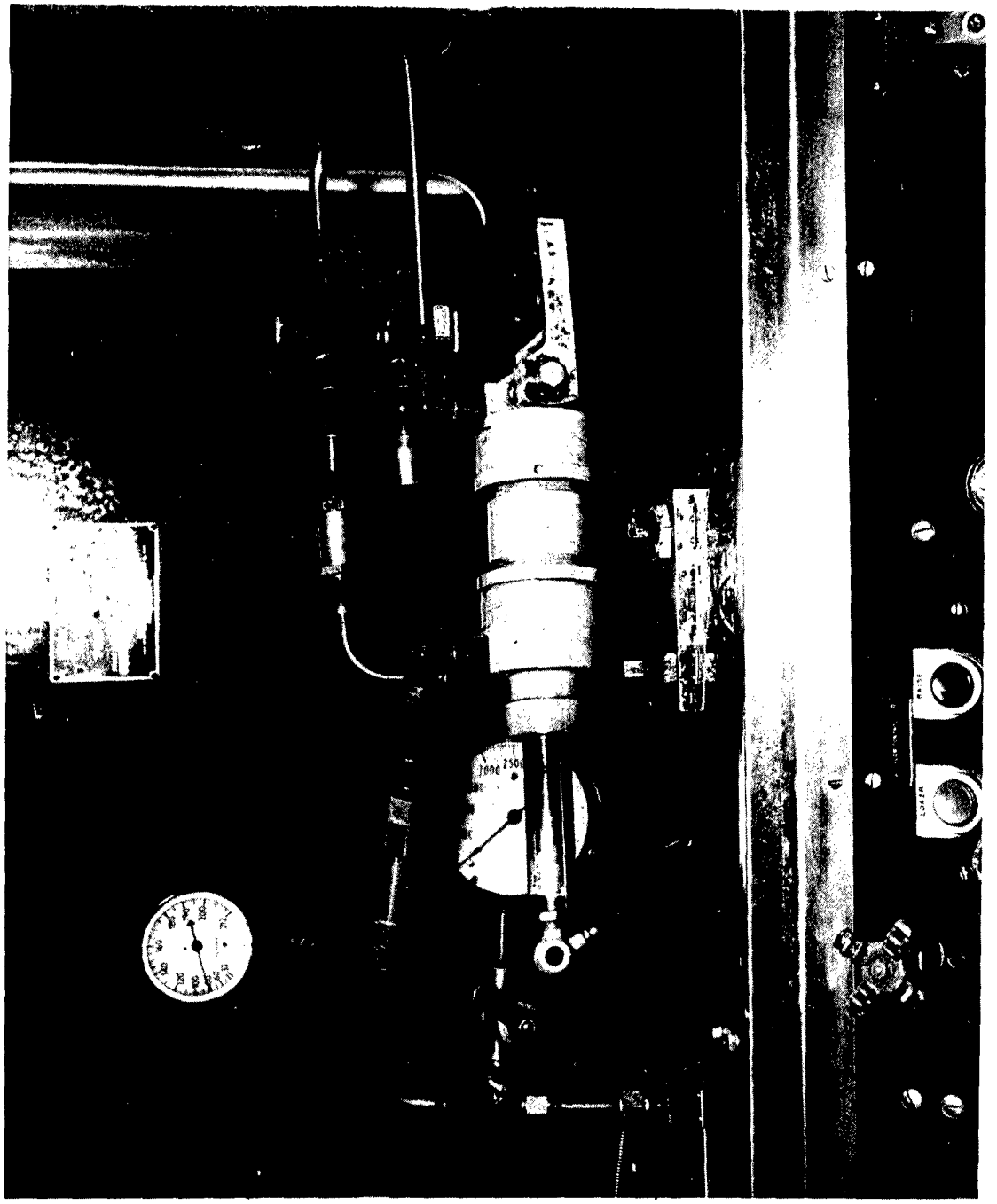
Photograph II

Equipment used for "Volumetric Capacity Tests"



Photograph III

Equipment and Set up for "Pressure Drop Tests"



Photograph IV

Equipment and Set up for "Endurance Tests"